# A FIRST COURSE IN
# WIRELESS

R.B.A.N.M's High School (Main)
LIBRARY
Acc/s 267
23/1/76

HUTCHINSON

38-56
HUT)
N26

3/6

R.B.A.N.M'S H.S (M) LIBRARY
B lore-42
Accession No; 1705
U.D.C. No: 538-56/HVII
Date; 5.7.81

N26

R. B. A. N. M'S EDUCATIONAL CHARITIES.
No.....
Date.....
BANGALORE.

# A FIRST COURSE IN WIRELESS

R.B.A.N.M'S H.S M LIBRARY
B lore 42
SC/267
Accession No: 1705
U.D.C: 538.56/HVI
Date; 5-7-81
N 26
~~Acc~~/ ~~SC~~ ~~267~~
~~26/1/76~~

TEXT-BOOKS ON

# Magnetism and Electricity

AND

# Electrical Engineering.

A FIRST COURSE IN MAGNETISM AND ELECTRICITY. By R. H. JUDE, D.Sc., M.A. *Third Edition.* 3s. 6d.

SENIOR MAGNETISM AND ELECTRICITY. By R. H. JUDE, D.Sc., M.A., and Professor JOHN SATTERLY, D.Sc., M.A. 6s. 6d.

MATRICULATION MAGNETISM AND ELECTRICITY. By R. H. JUDE, D.Sc., M.A. and Professor JOHN SATTERLY, D.Sc., M.A. *Second Edition.* 6s. 6d.

INTERMEDIATE TEXT-BOOK OF MAGNETISM AND ELECTRICITY. By R. W. HUTCHINSON, M.Sc., A.M.I.E.E. *Second Edition.* 9s. 6d.

ADVANCED TEXT-BOOK OF MAGNETISM AND ELECTRICITY. By R. W. HUTCHINSON, M.Sc., A.M.I.E.E. In Two Vols. *Second Edition.* 12s. 6d.

JUNIOR TECHNICAL ELECTRICITY. By R. W. HUTCHINSON, M.Sc., A.M.I.E.E. *Second Edition.* 4s. 6d.

TECHNICAL ELECTRICITY. By H. T. DAVIDGE, B.Sc., M.I.E.E. and R. W. HUTCHINSON, M.Sc., A.M.I.E.E. *Fourth Edition.* 12s. 6d.

ELECTRICAL ENGINEERING, CONTINUOUS CURRENT. By W. T. MACCALL, M.Sc., M.I.E.E. *Second Edition.* 15s.

ELECTRICAL ENGINEERING, ALTERNATING CURRENT. By W. T. MACCALL, M.Sc., M.I.E.E. 15s.

A FIRST COURSE IN WIRELESS. By R. W. HUTCHINSON, M.Sc., A.M.I.E.E. 3s. 6d.

A TEXT-BOOK OF WIRELESS TELEGRAPHY AND TELEPHONY. By W. GREENWOOD, B.Sc., A.M.I.E.E., A.C.G.I. 5s. 6d.

# A FIRST COURSE IN

# WIRELESS

R B A N S H S M LIBRARY
B'lore-42
Accession No; 1705.
U.D.C No: 538.56/HUT)
Date; 5-7-81. N26

BY

ROBERT W. HUTCHINSON, M.Sc., A.M.I.E.E.

AUTHOR OF "ADVANCED TEXT-BOOK OF MAGNETISM AND ELECTRICITY" "INTERMEDIATE TEXT-BOOK OF MAGNETISM AND ELECTRICITY" "JUNIOR TECHNICAL ELECTRICITY"
JOINT AUTHOR OF "TECHNICAL ELECTRICITY," "WORKED PROBLEMS IN HEAT AND HEAT ENGINES"
REVISING EXAMINER IN MAGNETISM AND ELECTRICITY AND ELECTRICAL ENGINEERING, UNION OF EDUCATIONAL INSTITUTIONS
LATE PRINCIPAL, MUNICIPAL TECHNICAL SCHOOL, AND JUNIOR DAY TECHNICAL AND COMMERCIAL SCHOOLS, SMETHWICK

*Second Impression*

LONDON: W. B. CLIVE
University Tutorial Press Ld.
HIGH ST., NEW OXFORD ST., W.C.
1926

~~2076~~
D65,4 (T2)
N26

R.B.A N.M'S H.S (M) LIBRARY
B lore 42
Accession No ; 1705
U.D.C No : 538·56/HUT
Date; 5·7·81

PRINTED IN GREAT BRITAIN BY THE UNIVERSITY TUTORIAL PRESS LD. AT THE
BURLINGTON PRESS, FOXTON, NEAR CAMBRIDGE.

R. B. A. N. M'S EDUCATIONAL CHARITIES
No. 103
Date.
BANGALORE.

# PREFACE.

THE object of this book is to give the reader a clear insight into the fundamentals and practical working of wireless telegraphy and telephony, and to base his knowledge from the outset on sound scientific principles. To this end no previous knowledge either of the science of electricity or of wireless is assumed, and a brief but sufficient account of all the absolutely necessary theory is given in a *simple, rational,* and *scientific* way which will neither conflict with the ideas of the pure physicist nor result in the practical student having to abandon his conceptions as his studies lead him into the higher stages of the subject.

The book is intended for beginners, for wireless amateurs and experimenters, for students in Secondary and Technical Schools and Evening Technical Classes, and for that ever increasing body of men and women who are not satisfied with merely "listening in" but who are inquisitive as to the why and the wherefore of things: and although mathematics and mathematical physics have been purposely avoided, it is hoped that the book may at least prove of interest even to the more advanced student who already possesses a knowledge of electricity and electrical engineering.

There has been a tendency in the past for many wireless workers to ignore all but the practical side of this fascinating subject on the assumption that they would be able to acquire all the necessary theory from practical experience alone, but this is altogether a fallacy. It is only by a proper understanding of fundamental theory, of the scientific principles underlying the construction and action of the various appliances, of the why and the wherefore of the various transmission and reception circuits in use, that the student will be able to carry out his experimental work and devise circuits in wireless with intelligence and with every confidence of success. And the really essential theory is not difficult to acquire.

The point of view of the writer is that of one who has had many years' experience with students of all ages in Day Schools, Technical Institutes, and University Classes, and over twenty years' experience with experimental wireless. This will explain why certain portions of the book are treated at comparatively great length, why certain sections are particularly emphasised, and why simple theory runs hand in hand with the more popular practical applications throughout the book.

The book combines scientific principles with wireless practice, and the difficulties encountered by beginners have been borne in mind throughout. Great care has been devoted to accurate principles and definitions and to the use of simple language in explaining them. Modern theory is introduced from the beginning, and the whole is given an applied bias from the outset, introducing the main facts and the various components of practical wireless as they logically arise. The essentials in the production, propagation, and detection of wireless waves are dealt with as fully as the scope of the book permits, and numerous wireless circuits are discussed in full detail. Of the 216 illustrations, a few have been reproduced by kind permission from *A Text Book of Wireless Telegraphy and Telephony* by W. Greenwood, B.Sc., A.M.I.E.E., but most have been prepared specially for the book.

The thanks of the author are due to Mr. Ayton Robert W. Hutchinson, M.Sc., Miss M. Rigden, B.Sc., and Miss Roberta Irene Hutchinson, M.B., Ch.B., for assistance with the diagrams and proofs. Thanks are also due to certain manufacturing firms, mentioned in the text, who have kindly supplied blocks for the printing of certain illustrations.

ROBERT W. HUTCHINSON.

CAMBRIDGE, 1926.

# CONTENTS.

CHAPTER PAGE

I. ELECTRICITY: ELECTRIC STRAINS IN THE AETHER .. 1

II. MAGNETISM: MAGNETIC STRAINS IN THE AETHER ... 20

III. SOME UNITS AND SIMPLE ELECTRICAL THEORY ... ... 32

IV. BATTERIES ... ... ... ... ... ... ... 44

V. CAPACITY AND INDUCTANCE ... ... ... ... ... 60

VI. A FEW FACTS ABOUT ALTERNATING CURRENTS ... ... 87

VII. THE PRODUCTION, PROPAGATION, AND DETECTION OF "WIRELESS" WAVES ... ... ... ... ... 103

VIII. THE CRYSTAL AND THE VALVE ... ... ... ... 137

IX. AERIALS AND EARTHS ... ... ... ... ... 152

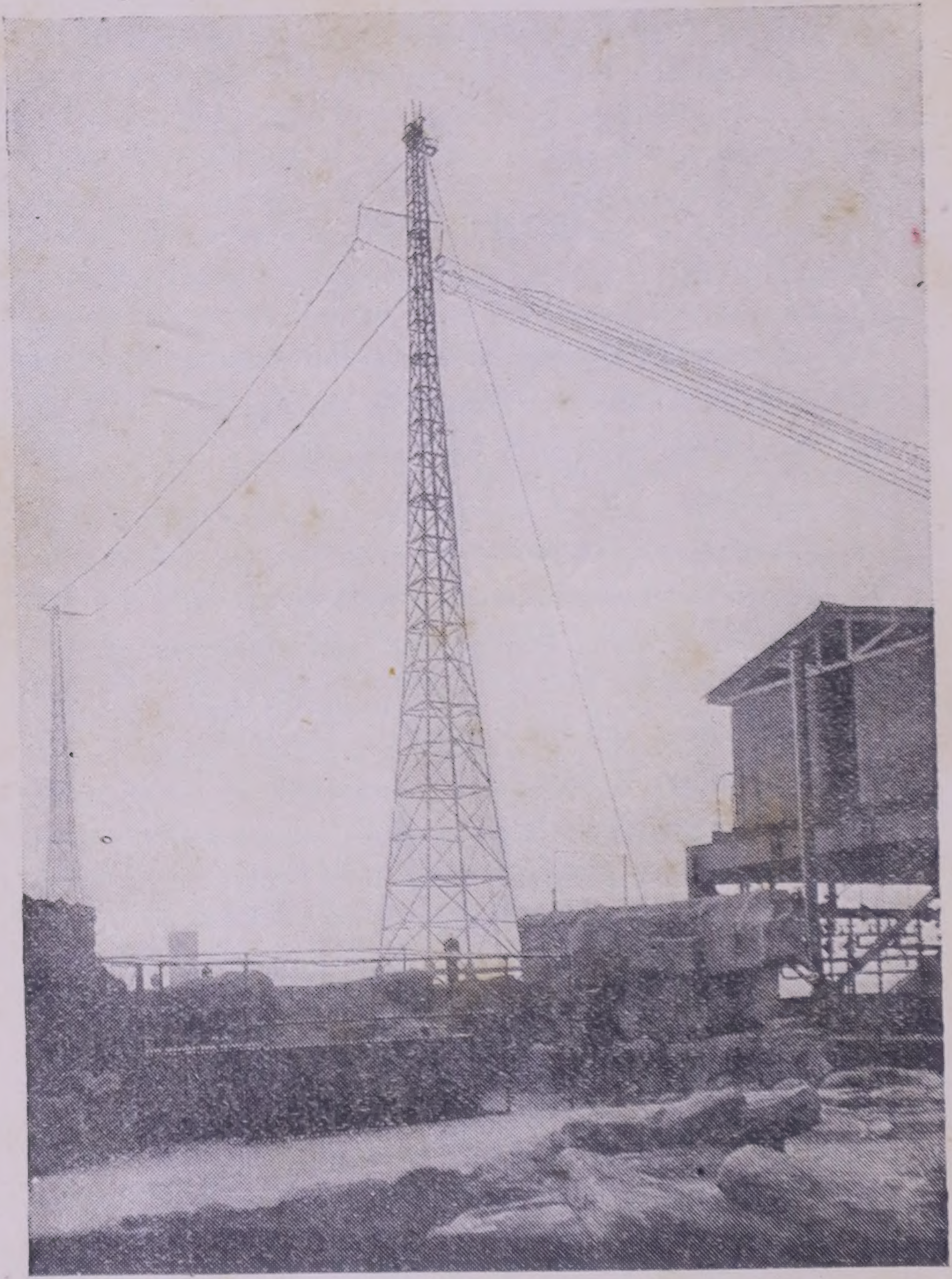
X. CRYSTAL RECEIVING SETS ... ... ... ... ... 163

XI. SINGLE VALVE RECEIVING SETS ... ... ... ... 179

XII. MULTIVALVE RECEIVING SETS ... ... ... ... 203

XIII. VALVE TRANSMITTERS: DIRECTIONAL WORK: THE BEAM SYSTEM OF WIRELESS TELEGRAPHY: WAVE LENGTHS IN BROADCASTING: TELEVISION ... ... ... 238

INDEX ... ... ... ... ... ... ... ... 257



View of Masts, etc., of the London Broadcasting Station.

(Reproduced by permission of Mr. J. Scott-Taggart, of the Radio Press, London.

# CHAPTER I.

## ELECTRICITY: ELECTRIC STRAINS IN THE AETHER.

1. **Electrification.**—The ancients were acquainted with the fact that pieces of amber and jet possessed, when rubbed, the property of attracting light bodies, and it is from the Greek name **ëlektron** (amber) that our word "electricity" is derived. It is now known that, with proper precautions, all substances, suitably rubbed, will attract to some extent such light articles as pieces of paper, bran, cork, pith, etc.; glass rubbed with silk, sealing-wax with flannel, and vulcanite with fur, do so in a marked degree, and particularly the last named. A substance endowed with this property is said *to be electrified, to be excited, to be charged, to possess a charge*, or *to be in a state of electrification*, and the unknown mysterious agent which is the cause of this state is named **electricity**. Bodies not endowed with the property mentioned are said to be electrically *neutral*.

2. **The Two States of Electrification.**—If a glass rod which has been rubbed with silk be brought near a ball of elder pith suspended by a dry silk thread from a suitable stand, the pith-ball will be attracted to the rod, and, after being in contact for a moment, will be repelled, from which it may be surmised that the ball becomes charged on touching the rod, and that when a neutral body takes a portion of the charge from an electrified one the two no longer attract, but repel each other.

Again, if a vulcanite rod which has been rubbed with fur be suspended from the stand by a dry silk thread, and a second vulcanite rod also rubbed with fur be brought near, the suspended one will be repelled; but a glass rod rubbed with silk will attract it. Similarly, if the electrified glass be suspended, a second glass rod excited with silk will repel it, but the vulcanite rod rubbed with fur will produce attraction.

Numerous early experiments of the above character with various substances led to the conclusions (1) that there were two states of electrification, (2) that bodies in similar states of electrification repelled each other, (3) that bodies in unlike states of electrification attracted each other.

**3. Positive and Negative Charges of Electricity.**—It was agreed to call the state of electrification exhibited by glass rubbed with silk, **positive,** and to say that the glass was "*positively*" *charged*; it was further agreed to name the state of electrification of vulcanite rubbed with fur **negative,** and to say that the vulcanite was "*negatively*" *charged*. Hence we have the important laws :—

(1) *Positively charged bodies repel each other.*

(2) *Negatively charged bodies repel each other.*

(3) *A positively charged body and a negatively charged one attract each other.*

So far we have not concerned ourselves with the rubber; but experiment proves that if a vulcanite rod be fitted with a fur cap to which is attached a dry silk thread, and if when electrifying the rod, the thread and not the fur be held in the hand, on separating, the vulcanite is negatively charged and the fur positively charged. Further, if, before separating, the two be brought together near an uncharged pith-ball, the latter is not affected in the least, from which it may be gathered that the two electrifications are equal, and are neutralising each other. Numerous tests all lead to the same conclusion, viz. *that both states of electrification are established at the same time and to an equal degree.*

In the light of modern electrical theory, this arbitrary naming of the charges in the first instance causes a certain amount of confusion in the mind of a beginner, but any difficulty he may experience at first will disappear as his studies proceed.

**4. Electricity—The Modified "One Fluid" Theory.**—Although it is now recognised that electricity is not a "fluid" in the sense assumed by Symmer and Franklin in their early fluid theories of electricity, a modification of what is called the "one fluid theory" due to Franklin may be used by the

A. M. S. HIGHER SEC SCHOOL LIBRARY
Sec
BANGALORE

beginner as explaining many facts in electricity more simply than any other theory.

It may be supposed, for example, that the vulcanite rod and the fur of the preceding experiments, when neutral, are each imbued with a definite or stock amount of something which we will call electricity. It may be further conceived that on rubbing the two together, electricity passes from the rod to the rubber, so that the rod will have a "deficit," and may be said to have a "negative charge"; the fur will have a "surplus" or a "positive charge," and, since the surplus on the rubber has come from the rod, the two "charges" will be equal and capable of neutralising each other.

Similarly, when glass is rubbed with silk, electricity passes from the silk to the glass, so that the former has the deficit or negative charge, and the latter the equal surplus or positive charge.

Of course, since the terms "positive" and "negative" were fixed arbitrarily, it is possible that what is called by consent the positive charge may be the deficit and the other the surplus, but there is no means of settling the question, and it really does not matter at present. It should also be noted that, according to this theory, *there are not two kinds of electricity but two states of electrification*, *i.e.* two electrical conditions, one due to a surplus, the other to a deficit of electricity.

**5. Generators do not make Electricity.**—There is another point which the reader must notice in the above, and that is that when we electrify a body we do not *make* electricity. Further, dynamos are used in running factories, huge electric generators are used in power stations for heating and lighting and traction, magnetos are used on motor cars and motor cycles, batteries are used for electric bells, etc., but none of these generators, as they are called, *make* electricity: they no more manufacture electricity than a pump manufactures water. Electricity is in everything, all matter is really composed of it, and dynamos, batteries, etc. are merely pumps which give "head" or "pressure" to the electricity and make it able to do something it could not do before. The reader will realise this as his studies proceed.

**6. Electricity—The Modern Electron Theory.**—The student has often heard of **atoms**, which have long been regarded as the ultimate and indivisible parts of all matter—the fundamental bricks, in fact, of which everything is built up. This page for instance is not a "solid" white body with black marks on it : it really consists of millions upon millions of little separate bodies—atoms—all in motion and with comparatively big spaces between them.

In recent years, however, the existence of particles more minute than any previously known in science has been definitely established, the mass of each being about $\frac{1}{2000}$ of the mass of a hydrogen atom (the lightest atom known), and each being always associated with a definite negative charge—in fact, the particle is probably entirely electrical, *i.e.* composed solely of negative electricity. The name **electron** has been given to these particles. From whatever source these electrons are obtained and examined—and they can easily be obtained in various ways and from various substances—the mass and the negative charge are always the same : charges smaller than the electron cannot be obtained, so that this charge is a natural unit of electricity, and is sometimes referred to as an "atom of electricity."

Now the modern theory of the construction of matter is that an atom of any substance is composed of a nucleus or centre of positive electricity, called a **proton**, surrounded by these atoms of negative electricity or electrons in rapid motion. The difference in size between the proton and an electron is similar to that between St. Paul's Cathedral and one of the many pigeons in its vicinity. The nucleus attracts its electrons with a force very much greater than gravity, but they do not "fall into it" because they are revolving so rapidly—for the same reason, in fact, that the earth does not fall into the sun. As far as charge is concerned the proton's positive charge just balances the negative electronic charges when the atom is neutral.

Again, the number and arrangement of the electrons in the atoms of a substance determine its properties—determine in fact what the substance is. Thus a system of one kind gives us what we call zinc, a system of another kind gives iron, and so on. Taking in further illustration the elements as given in the chemists' " Periodic Table," a neutral atom of hydrogen probably consists of one revolving (negative) electron outside the nucleus, and a nucleus consisting of a proton with an equal free positive charge : a neutral atom of helium has two revolving electrons outside the nucleus, and the latter consists of two equal free positive charges, lithium has three of each, beryllium four, boron five, carbon six, nitrogen seven, oxygen eight, and so on, up to uranium with ninety-two.

The removal of electrons from the atoms of a substance may change the properties of the substance altogether and produce what is known to us as quite a different substance. On the other hand, the removal of electrons (or the addition of electrons) may simply produce electrification, and that is the case which concerns us at present.

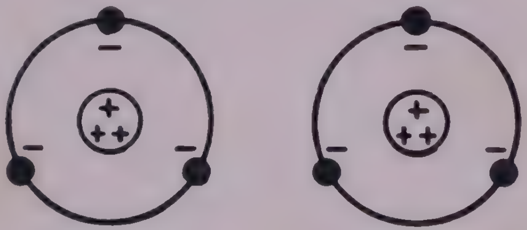

Neutral Atom. Neutral Atom.

Fig. 1.

In Fig. 1 are shown two atoms, each consisting of a positive nucleus carrying a treble charge and three electrons. In this case the attractions and repulsions balance and the atoms are neutral. In Fig. 2 one of the electrons has been detached from one atom and absorbed by the other, so that the first atom is positively charged, since the positive nucleus predominates, and the second atom is negatively charged, since the negative electrons predominate. The positive portion of the first atom tries to recapture the electron it has lost and to which it is entitled (or to get hold of another one in place of it), and the electron is equally anxious to get back : thus the attraction between the two oppositely charged atoms is due to the attraction between the free positive nucleus charge in one and the surplus electron in the other.

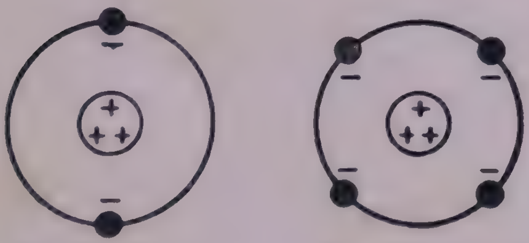

Positive Atom. Negative Atom.

Fig. 2.

An atom which has lost an electron is usually spoken of as a **positive ion,** and one which has gained an electron as a **negative ion.** The force between a positive ion and an electron is enormous, almost beyond our comprehension : if gravity were as great, a man would weigh hundreds of tons.

In Fig. 3 we have two atoms which have each lost an electron, so that both are positively charged. In this case the repulsions overbalance the attractions, and the result is repulsion. A similar result follows in the case of two atoms which contain an extra electron each, and are, therefore, negatively charged.

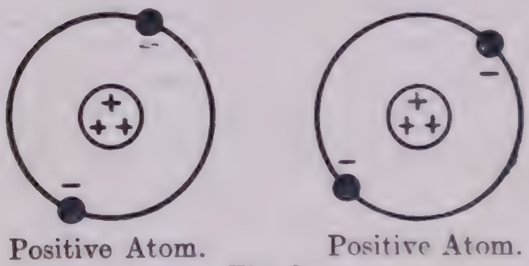


Fig. 3.

When vulcanite is rubbed with fur some electrons are detached from the fur atoms and transferred to the vulcanite atoms. The vulcanite has a surplus of (negative) electrons, and is negatively charged : the fur has a deficit of electrons, and is positively charged.

When we say that electricity is flowing along a wire we mean, according to this theory, that there is a movement of electrons in the wire. It must be remembered, however, that, as the electrons are negative, they move in the opposite direction to what is usually regarded as the " direction of the current " (see Art. 17).

**7. Conductors and Insulators—The Modified " One Fluid " Theory.**—It can easily be shown that if bodies are held in the hand, some (*e.g.* glass, wax, vulcanite, etc.) can readily be electrified by friction, whilst others (*e.g.* metals) give no signs of electrification. The difference is due to the fact that the first are *insulators*, the second *conductors*. **A conductor is a substance which readily allows electricity to flow along it ; an insulator is a substance which does not allow electricity to flow along it.**

Consider, then, a glass rod held in the hand and rubbed with silk. The part rubbed becomes positively electrified and (using the Franklin theory) the " surplus " remains there, for the rod, being an insulator, does not allow the electricity to flow along it to the hand, from which it would readily pass to the earth, since the human body is a good conductor. Similarly, the "deficit" on the vulcanite rod after it is rubbed with fur cannot be made up by a flow of electricity from the earth, through the body and hand of the experimenter, because vulcanite is an insulator.

A brass rod, held in the hand and rubbed with indiarubber, becomes positively electrified, but the electricity at once flows along it to the hand, and down the body to the earth; by fitting the brass rod with an insulating handle of glass, wax, vulcanite, etc., it can be electrified.

Again, if an electrified conductor be placed in contact with another insulated but non-electrified conductor, it will be found that the former at once transfers a portion of its electrification to the latter; using the Franklin theory, if the charged conductor be positive, some of the "surplus" passes to the uncharged conductor, so that both are positively charged; whilst if the charged conductor be negative, the "deficit" is *partly* made up by a flow of electricity from the uncharged conductor, so that both exhibit a "deficit," *i.e.* both are negatively charged. It is customary to say, in the last case, that the charged conductor "shares its negative charge" with the uncharged conductor.

The best conductors are the metals, and amongst these annealed silver stands first. Amongst the good insulators are *dry* air, dry glass, paraffin wax, amber, mica, vulcanite, shellac, indiarubber, silk, porcelain, sealing-wax, etc.

**8. Conductors and Insulators—The Electron Theory.**—If the electron theory be used in the above explanation it will be necessary to say, in the case of the glass rod which has a *deficit of (negative) electrons*, that electrons cannot get along it from the earth to make up the deficit, and in the case of the vulcanite which has a *surplus of electrons*, that electrons cannot pass along it to earth to get rid of the surplus: in the case of the brass, electrons can pass along it quite readily.

As a matter of fact, on the electron theory the difference between a conductor and an insulator is this:—An atom of a conductor contains one or more electrons that are loosely bound to the nucleus or proton : they are comparatively easily detached and can "flow along" the conductor in a manner which is explained later. In the atom of an insulator, however, the electrons are, in comparison, tightly bound and not easily detached (except by some very big electrical pressure) ; hence they do not "flow along" the insulator as a conductor's electrons do.

**9. Conductors and Insulators used in Wireless.**—In wireless receiving sets, copper, aluminium and brass are the chief substances used as conductors. *Copper* is mainly used in the form of wire : for internal connections tinned copper wire is largely employed owing to the ease with which it can be soldered. *Aluminium* is coming more and more to the front in electrical work. It costs less than copper and it is very light and easily drilled and filed ; on the other hand it is not so good a conductor as copper and has a lower tensile strength, and the soldering of it presents a certain difficulty. In wireless it is mainly used for the plates in variable condensers. *Brass* is an alloy of copper and zinc in various proportions which is extensively used in the form of sheets, rods, tubes, nuts, screws, terminals, etc.

*Shellac* is often employed as a practical insulator. It is obtained from an insect which deposits its eggs on certain trees in India : these are placed in bags, heated, and the liquid squeezed out, which latter forms crude shellac. Shellac dissolved in methylated spirits produces *shellac varnish*, and this is the form in which it is mainly used. It is necessary to heat an article after varnishing in order to drive out moisture.

*Mica* and various modifications of mica are also used as insulating materials. The mineral mica consists of a double silicate of potassium and aluminium : it can be obtained in very thin layers, is influenced but slightly by temperature changes, and does not absorb moisture, which rapidly lessens insulation. Mica is largely used in making fixed condensers. *Micanite cloth* and *micanite paper* consist of mica cemented to cloth and paper respectively.

*Paraffin wax* is a good insulating material which is largely used for improving the insulating powers of other materials and protecting them from damp.

*Ebonite*, a composition of rubber and sulphur, is extensively employed in wireless as an insulating material for panels, etc. As the shiny surface may often prove a conductor, it is essential that the surface should be given a " matt finish " by rubbing with emery cloth. Matt ebonite can of course be purchased. If ebonite becomes of a brownish colour on matting, the black colour can be restored by rubbing with a cloth soaked in oil. *Radion Mahoganite* is a type of ebonite which is of a mahogany brown colour and grained like wood, and the surface of this does not require to be matted.

A *moulded composition* is used for dials, knobs, etc. in receiving sets.

Other conducting and insulating materials are employed which will be referred to as the necessity arises.

**10. Electrostatic Induction.**—Consider an insulated body *C* (Fig. 4) in the centre of a room, and let a positive charge be given to it. It is believed that this gives rise to a pressure extending right throughout the insulating medium (air), but diminishing at first rapidly and then slowly as we recede from the body *G* to the earth-joined bodies in the room; that in consequence the insulating medium is strained until it sets up an opposing influence which exactly balances the forward pressure due to the charged body.

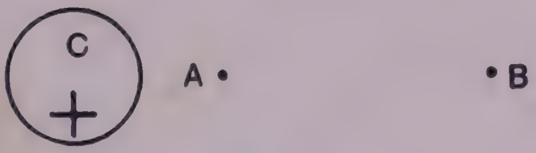


Fig. 4.

Taking, then, any two points *A* and *B* (Fig. 4), the pressure at *A* exceeds the pressure at *B*; adopting the Franklin theory, this pressure difference tends to drive electricity from *A* to *B*, but the medium sets up an opposing influence which balances the forward pressure, so that the insulating medium is strained, but there is no " flow."

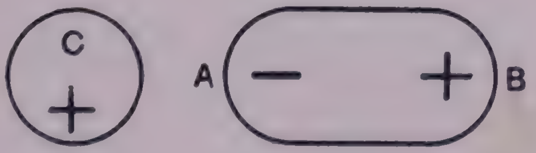


Fig. 5.

Now let a conductor (Fig. 5) be placed so as to connect *A* and *B*. The pressure difference tends to drive electricity from *A* to *B*, and the conductor being unable, like an insulator, to set up an opposing influence, permits the flow; thus electricity flows from *A* to *B* until uniform pressure exists over the whole conductor. Clearly, then, the end *A* will have less than its normal amount, *i.e.* a negative charge, and *B* will have an equal surplus, *i.e.* a positive charge. Remembering, too, how the pressure varies as we travel from *C* outwards, it will be apparent that the displacement of the conductor's electricity will be greater the nearer the conductor is to the charged body.

If *C* be negative, its pressure is below that of the earth, *i.e.* of the walls, etc., of the room. Thus the pressure *rises* as we recede from it, being therefore greater at *B* than at *A*. On placing the conductor in position, electricity flows from *B* to *A*; *B* in this case exhibits a negative charge, and *A* an equal positive charge.

On the electron theory the positively charged sphere *C* of Fig. 5 draws electrons out of the atoms of *AB* towards it, so that at *A* we have a surplus of electrons, whilst at *B* we have the positive ions—the atoms from which the electrons have been wrenched : *A* exhibits a negative charge and *B* a positive charge. A somewhat similar explanation can be applied to the case where *C* is negatively charged.

These actions are referred to as **electrostatic induction** : *C* is called the inducing body, *AB* the body acted on inductively, and the insulating medium which transmits these influences, itself playing a vitally important part in the action, is known as the **dielectric.**

On interposing a solid dielectric such as glass, wax, mica, etc., or a liquid dielectric, between *C* and the conductor *AB*, the inductive effects will be still more marked, for these dielectrics permit the influence to take place through them better than air, and are said to have a higher **specific inductive capacity.** It has been indicated that the nearer the two bodies are together the better is the result, and *the introduction of these solid dielectrics is (electrically) equivalent to shortening the air space*; thus a piece of mica 5 cm. thick is equivalent to an air thickness of 1 cm.; its specific inductive capacity is 5, that of air being taken as unity (Art. 67). Specific inductive capacity is also called the **dielectric constant.**

**11. Electrical Potential.**—One of the most important points in the study of electricity is what is known as **electrical potential**, and it is essential that the student should get a thorough grasp of the idea. It will help towards this end if the following three analogies be first considered, bearing in mind, however, that though the analogies are helpful, they are rather faulty in detail and must not be pushed too far.

**12. Electrical Potential—Analogy to Temperature.**—It is well known that heat flows from a body at a high temperature to a body at a low temperature. If two bodies be connected together by a conductor of heat, and no heat passes from one to the other, the two bodies are at the same temperature; if the two bodies are at different temperatures, then heat will flow from the one at the higher temperature to the one at the lower temperature, and this flow will continue until the two come to the same temperature.

Further, if a cupful of boiling water be mixed with a gallon of colder water, heat will flow from the former to the latter, although the latter really contains more heat; thus *the difference in temperature*, not the difference in the amount of heat, *really settles the direction in which heat will flow.*

**13. Electrical Potential — Analogy to Water Level.**—It is also well known that water flows from a high water level to a low water level. Thus, if the two vessels of Fig. 6 contain water as indicated, then on opening the stop-cock water will flow from *A* to *B*, and the flow will continue until the two come to the same level. The actual quantity of water in *B* may be considerably greater than the quantity in *A*; *it is the difference in level*, not the difference in the amount of water, *which settles the direction in which the water will flow.*

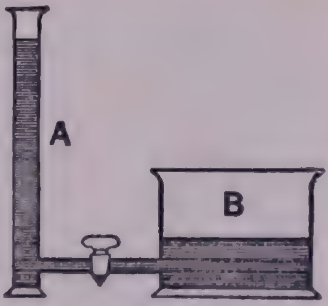


Fig. 6.

**14. Electrical Potential—Analogy to Air Pressure.**—Again, consider an indiarubber bag fitted with a stop-cock and a pressure-gauge. Pump air into the bag so that it contains more than its normal amount and then close the stop-cock.

The gauge will indicate that the air pressure inside is greater than that outside. Open the stop-cock; *air will pass from the bag into the atmosphere*, i.e. from the region of higher pressure to that of lower pressure, and this will continue until the bag has its normal amount, and the gauge indicates that the air pressures inside and outside are the same.

Now draw air out of the bag so that it contains less than its normal amount, and then close the stop-cock. The gauge will indicate that the air pressure inside is less than that outside. Open the stop-cock; *air will then pass from the atmosphere into the bag*, i.e. from the higher pressure to the lower pressure, and this will continue until the bag has its normal amount and the gauge indicates that the air pressures inside and outside are the same.

Further, take two bags and arrange matters so that the air pressure in one is higher than the air pressure in the other. Join the two cocks by indiarubber tubing, and then open the stop-cocks. It will be found that *air passes from the bag at the higher pressure to the bag at the lower pressure*, and that this continues until the air pressure is the same in both bags. If, to begin with, the bags are at the same pressure, then on opening up the communication there is no flow of air. By considering a large bag and a small one, it will be readily seen that it is the difference in pressure, not in the amount of air, which settles the direction of flow.

Again, in measuring temperatures by a Centigrade thermometer, the temperature of melting ice is taken as the standard of reference or the zero; temperatures higher than this are spoken of as *positive* temperatures, and temperatures lower than this are called *negative* temperatures. Similarly, in measuring heights of mountains, etc., the sea-level is taken as the zero level; distances above sea-level might well be called positive, and distances below sea-level negative.

**15. Electrical Potential in Greater Detail.**—In the study of electricity the expression *electrical pressure*, or *electrical tension*, or **potential**, has much the same meaning as temperature, level, and pressure in the three preceding considerations. Thus, consider an insulated and isolated positively charged conductor. Using the Franklin theory, if this be put in conducting communication with the earth, its "surplus" passes to earth, i.e. *electricity flows from it to the earth* and the conductor becomes neutral. The reason for this is that its electrical pressure is above that of the earth, and the fact is expressed by saying that *it is at a higher potential than the earth.* Since the earth is taken as the standard of reference or zero of potential, the conductor is said to be at a *positive potential.* Of course, after the momentary flow the potential of the conductor is the same as that of the earth, viz. *zero.*

Consider now an insulated, isolated, negatively charged conductor. If this be earthed, *electricity flows from the earth to it* until its "deficit" is made up and the conductor becomes neutral. This is because its electrical pressure is below that of the earth; *it is at a lower potential than the earth,* and is said to be at a *negative potential.* After the flow the potential of the conductor is *zero.*

It should be noted that the potential of the earth is regarded as constant, and as totally unaffected by any electricity which we give to it, or take from it, in our experiments; *the potential of an earthed conductor is therefore always zero.*

Again, if two conductors at different potentials be joined together, *electricity will flow from the one at the higher potential to the one at the lower potential,* thereby lowering the potential of the former and raising the potential of the latter, *until the two come to the same potential.* The actual "charge" on the body at the higher potential may be *less* than the "charge" on the one at the lower potential; it is not the amounts of the charges, *but the relative potentials,* which settle the direction in which the electricity will flow, and, as will be seen later, the potential of a body depends on its size and other factors as well as on its actual charge.

From the preceding it follows that, if a *conductor* is in a state of electrical equilibrium, all parts of it are at the same potential; this does not follow in the case of *insulators.*

To summarise:—**The potential of a body is its electrical pressure above or below that of the earth; it is the electrical condition which determines whether electricity will flow from the body to the earth, or from the earth to the body, when they are connected by a conductor.**

*A body is at a positive potential if electricity flows, or tends to* *flow, from it to the earth, and it is at a negative potential if electricity flows, or tends to flow, from the earth to it. It is at zero potential if there is no tendency for electricity to flow from one to the other.*

*Similarly, a body A is at a higher potential than another one B if electricity flows, or tends to flow, from A to B when they are joined, and they are at the same potential if there is no tendency for electricity to flow between them.*

Further :—(*a*) Potential Difference (P.D.) is the necessary condition for a transfer of electricity. (*b*) All parts of a *conductor* in electrical equilibrium are at the same potential. (*c*) The potential of an earthed *conductor* is zero.

In considering the above from the point of view of the movement of electrons, the student must remember that the latter, being negative, move from what we have called the lower to what we have called the higher potential.

**16. Electrostatic Induction from the Point of View of Electrical Potential.**—Referring again to Fig. 4, *C* is at a positive potential due to its positive charge, and this produces a positive potential throughout the whole of the insulating medium (air), which latter potential decreases from its positive value at *C* (at first rapidly and then more gradually) to zero at all earth-connected bodies in the room. The medium is "strained," but there is no "flow," for the medium is an insulator and does not permit it.

When the conductor *AB* is placed in position, however, then, since the end *A* is at a higher potential than *B*, electricity flows from *A* to *B*, so that *A* exhibits a negative and *B* a positive charge. The negative charge at *A* lowers the potential of that end, and the positive charge at *B* raises the potential of that end, so that when everything is quite steady the whole conductor *AB* is at a uniform (positive) potential.

If *C* be negatively charged it is at a negative potential, and produces a negative potential throughout the insulating medium, the actual potential of the medium *rising* from its negative value at *C* to zero at the earth. In this case *B* is at a higher potential than *A*, and when the conductor is placed in position electricity flows from *B* to *A*, so that *B* exhibits a negative charge and *A* a positive one. The negative charge at *B* lowers the potential there, and the positive charge at *A* raises the potential there, so that when all is steady the whole conductor *AB* is at a uniform (negative) potential.

**17. How Electricity "Flows" along a Wire.**—We have seen that in order to have a flow of electricity from the end *A* to the end *B* of a conductor—say a copper wire—the end *A* must, somehow or other, be kept at a higher potential than *B*, in which case electricity will flow from the high potential *A* to the low potential *B* : this flow is spoken of as a *current of electricity*.

The above was arbitrarily chosen by the pioneers of electrical theory as the direction of current flow, and it is still used to-day. On the other hand, modern electrical theory—the electron theory—and particularly the properties of the valve used in wireless, demand that the flow be considered as a movement of negative electricity or electrons in the opposite direction, *i.e.* from the low potential *B* to the high potential *A*. This *apparent* contradiction of current direction is very confusing to a beginner, but the difficulty will disappear on further reading. The older idea is often referred to as the **conventional current** and the newer as the **electronic current.**

Now how does this "flow of electrons" from *B* to *A* take place? Most students know what a battery is, so to fix ideas let us imagine that the end *B* of the wire is joined to what is called the negative pole or low potential pole of a battery, whilst *A* is joined to what is called the positive pole or high potential pole of the battery : in this way *A* is kept at a higher potential than *B*.

The action of a battery, as will be seen later, is simply this ; it causes an excess of electrons to be piled up at the negative pole, and at the positive pole an excess of positive ions, *i.e.* atoms which have lost an electron. Now let us concentrate our attention on one of the free electrons at the negative pole. This electron rushes into an atom at the end *B* of the wire, and it does so with such force that it drives out one of the atom's own electrons and takes its place. This evicted electron dives into the next atom, driving out an electron and taking its place. And so this goes on from atom to atom all along the wire, until finally at *A* an evicted electron is taken in by a positive ion waiting, as it were, for it. As to what happens next, the student need not trouble at present—that is the story of how a battery works.

Of course, in practice, it is not a matter of one electron entering the end *B* and another leaving the end *A* of the wire, but millions upon millions per second.

In the chapters which follow we shall mainly use the conventional current, drawing frequent attention, however, to the electronic current, so as to accustom the student to both points of view. In certain cases it will be necessary to use the electronic current, but in these cases special attention will be directed to the fact.

**18. Electric Field. Electric Lines of Force.—An electric field is the space surrounding an electrified body within which the influence of the charge extends.** A free, small, positive charge placed at any point in the field will be urged by a definite force in a definite direction, which latter is indicated by what is called a **line of electric force** passing through the point in question. **A line of electric force is a curve such that the tangent at any point gives the direction of the electric force at that point.** The positive direction of a line is the direction in which a free *positive* charge tends to move : in some of the diagrams which follow arrows indicate the positive direction of the lines of force.

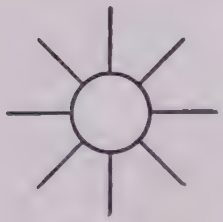


Fig. 7.

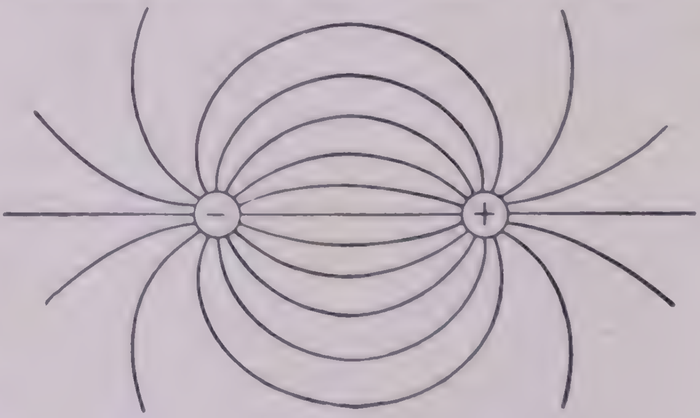


Fig. 8.

**19. Different Cases of Electric Lines of Force.**—Fig. 7 shows the lines of force in the case of a positively charged sphere in the centre of a large room : the lines start from the positive charge and end on the negative charge induced on the walls, etc., of the room. Fig. 8 gives the case of two equal conducting spheres with equal and opposite charges, whilst Fig. 9 gives the case of two equal positive point charges. Fig. 10 shows two positive charges in the ratio 4 : 1 ($A = +20$, $B = +5$), Fig. 11 gives the case of a charged body $C$ acting inductively on the conductor $AB$, and Fig. 12 shows a positively charged ball $A$ inside an insulated hollow conducting sphere $B$ but not at the centre of the latter : here the distribution of the charge on the inside of $B$ is irregular, but outside it is uniform, and further, the induced charges on $B$ are each equal to the charge on $A$.

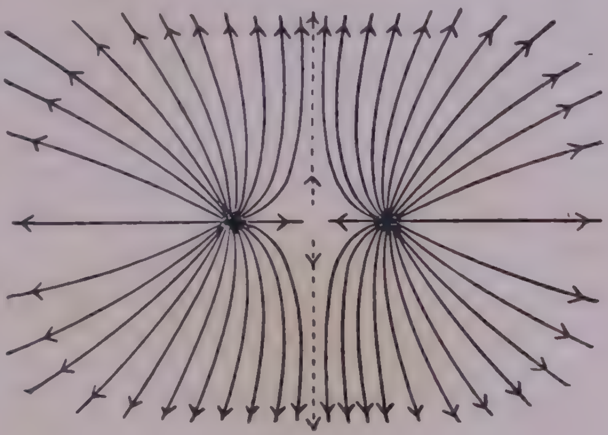


Fig. 9.

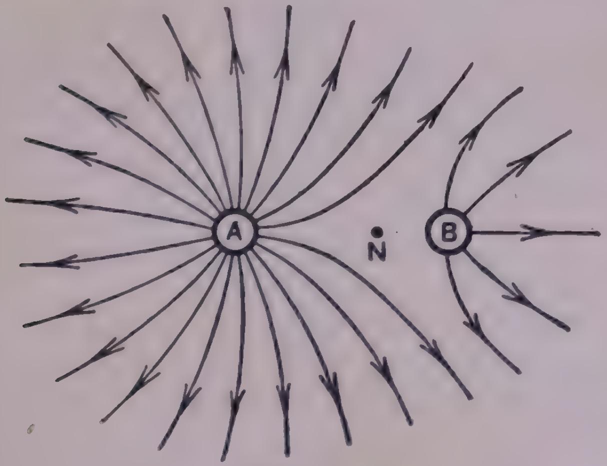


Fig. 10.

In all cases the lines start from a positive charge and end on a negative charge somewhere. It should be noted that whilst lines from a positive charge seek a negative charge, lines associated with like charges turn away from each other. It should also be noted that lines of force *do not pass through a conductor* but end on its surface.

In order to explain attraction and repulsion and inductive action, Faraday imagined these lines of force to be, so to speak, real connections between the positive and negative charges, and further, that each line tended to contract in the direction of its length, whilst lines proceeding in the same direction tended to repel each other laterally. Thus longitudinal contraction will account for the attraction between unlike charges (examine Fig. 8), and lateral repulsion will afford an explanation of the repulsion between like charges (examine Fig. 9).

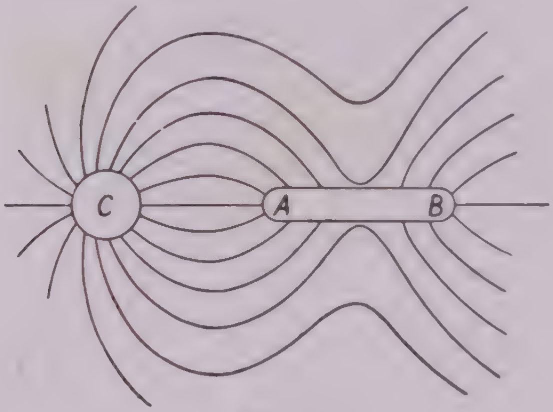


Fig. 11.

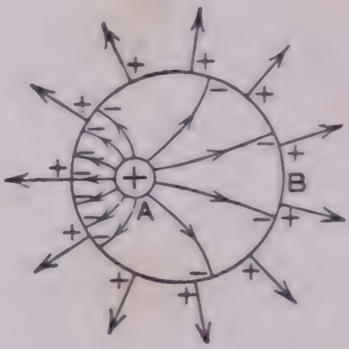


Fig. 12.

**20. The Aether.**—Scientists suppose that all space and all matter is pervaded with a medium called the **luminiferous aether** or simply the **aether**. This medium is invisible, odourless, practically weightless, infinitely tenuous, and elastic : it permeates and fills all matter and all space : we move about in it : the earth, the whole universe, is immersed in a limitless ocean of it : it is as essential to our existence as the air we breathe or the food we eat. Yet the exact nature of it is a much discussed question.

We know that heat and light come to us from the sun and both travel millions of miles before they reach the atmosphere, and on this heat and light our very existence depends. Moreover, heat and light are both forms of energy, and in order to transfer energy from one place to another some medium is necessary : incidentally a medium conveying energy is always *strained* in doing so. There must then be, in the space between our atmosphere and the sun, some medium which can be strained. Further, many facts in science, which cannot be mentioned at this stage, demand that this same medium must exist in our atmosphere and in all forms of matter, as well as in the space referred to. This all-pervading medium is the aether, and although its existence may be doubted by certain people, and some advocates of the recent Theory of Relativity (which the student may have heard about) may say that its conception is not necessary, the accumulated evidence of science is certainly on the side of its existence and necessity.

Sir Oliver Lodge, one of our wireless pioneers, in his *Talks on Wireless* says, " Do not hesitate to think and speak of the *aether of space* as the continuous reality which connects us all up and welds, not only us, but all the planets into a coherent system. Do not be misled by any misapprehensions of the Theory of Relativity into supposing that that theory dispenses with the aether merely because it succeeds in ignoring it. You can ignore a thing without putting it out of existence : and the leaders in that theory are well aware that for anything like a physical explanation of light or electricity or magnetism or cohesion or gratevation, the aether is indispensable. . . . It lies at the origin of all electrical developments, and forms the basis for this new and broadcast method of communication."

**21. Electric Strains in the Aether.**—We will go back for a moment to the electric lines of Art. 19. What exactly are these lines? Suppose, say, a positively charged body to be brought near a suspended negatively charged body; the latter will begin to move when the other is still some distance away. Some force is causing it to move and there must be a medium to convey the force.

If we move a body by pulling it with a rope or by pushing it with a stick the rope or the stick is the medium connecting the force applied and the body moved : and the rope or the stick, in transmitting the force, is *strained*. Now in the case of the two charged bodies the experiment works if they are in a vacuum, so the medium in question is not air. It must in fact be the aether, and the aether conveys the force from one body to the other because it is strained. We speak therefore of an **electric strain in the aether,** and the lines of Art. 19, which indicate the direction of the strain, are spoken of as **electric strain lines in the aether.** The aether, together with these and other aether strain lines dealt with in the next chapter are of the utmost importance in wireless.

# CHAPTER II.

## MAGNETISM: MAGNETIC STRAINS IN THE AETHER.

**22. Natural and Artificial Magnets.**—Most people know what a magnet is, and what its main properties are. The name magnet was applied at an early date to pieces of a mineral found in Magnesia in Asia Minor. These specimens of what is now called *magnetite*, or magnetic iron ore ($Fe_3O_4$), were found to possess the following properties :—

(*a*) They attracted pieces of iron or steel : if dipped in iron filings the latter clung to them. Often there were two end regions where the filings mainly adhered, and these regions of greatest attraction were subsequently referred to as the **poles** of the specimen.

(*b*) If a specimen with these poles were suspended by a thread, so as to be free to move in a horizontal plane, it came to rest in a definite direction, nearly north and south, the one end always pointing towards the north and the other end towards the south.

(*c*) If a piece of iron or steel were rubbed with the magnetite it was found to acquire the same properties as the magnetite itself.

Magnetite is called a **natural magnet**, whilst a bar of iron or steel which has been "magnetised" as above, or by more powerful methods to be mentioned later, is called an **artificial magnet**. *Permanent artificial magnets* are made of hard steel, and are usually horse-shoe shaped, or in the form of bars. *Electromagnets*, which are required to be quickly magnetised and to quickly lose their magnetic properties, are made of soft iron. Incidentally only iron and steel exhibit magnetic properties *to any marked degree*, and they are spoken of as the *magnetic substances.* Nickel, cobalt, and manganese show magnetic properties, but they are very weak compared with iron and steel.

**23. Poles of a Magnet.**—As in the case of the natural magnet, if a bar magnet be placed in iron filings the latter adhere mainly to regions near the ends, none clinging to the centre, and if the bar be suspended as in Fig. 13, or pivoted at the centre so as to be able to move in a horizontal plane, it comes to rest in a definite direction nearly north and south, the one end always pointing towards the north and the other end towards the south. The strongest parts of a magnet are, therefore, near the ends, and these are called the **poles**, the one which points towards the north being called the *north pole*, and the one which points towards the south, the *south pole* of the magnet.

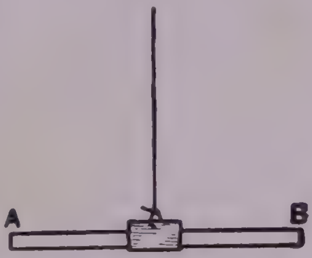


Fig. 13.

**24. Attraction and Repulsion between Magnetic Poles.**—If the north pole of a second magnet be brought near the north pole of the suspended magnet of Fig. 13, the suspended one will be found to be repelled, but if the north pole be brought near the south pole of the suspended magnet the result will be attraction. Similarly, if the south pole of the second magnet be brought near the south pole of the suspended magnet the result will be repulsion, whereas if it be brought near the north pole the result will be attraction. This establishes the fundamental law in magnetism, viz. *like poles repel and unlike poles attract.*

**25. Magnetic Induction.**—The important magnetic effect known as **magnetic induction** is easily shown by an experiment of the following type :—

Support a magnet *NS* (Fig. 14) vertically in a clamp. Bring a short piece of steel near the bottom end ; it clings to the magnet as shown at (*a*). Now bring another piece near the first ; it clings to the first as shown at (*b*). Now gently detach the upper piece from the magnet. The two pieces still cling together (*c*), and on testing the two separately by a suspended magnet (or watch chain compass), each will be found to be a magnet with poles as shown in the figure.

Modify this experiment by placing the magnet and the steel on a table so that they are not in contact (Fig. 15); it will be found that the result is the same, save that the pieces are not so strongly magnetised.

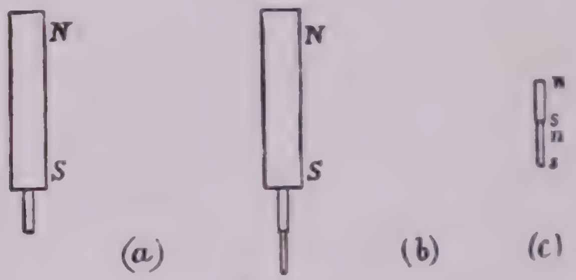


Fig. 14.

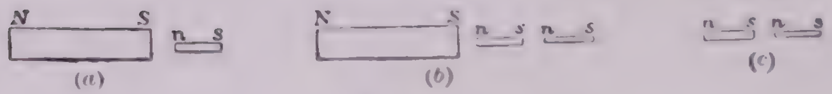


Fig. 15.

The effects shown above, viz., **the making of a piece of unmagnetised steel (or iron) into a magnet by the influence of another magnet with or without actual contact**, are referred to as "**magnetic induction,**" and the steel (or iron) is said to be *magnetised by induction.*

The "law of induced polarity" is settled from the experiment. Thus in Fig. 15 the end of the steel opposite the *south* pole of the magnet is a *north* pole. If a rod of steel or iron *CD* (Fig. 16) be placed near the north pole of a magnet *AB* the end *C* of the rod opposite the *north* pole is found to be a *south* pole. Hence **when a bar is magnetised by induction the end of it nearest the inducing pole acquires polarity opposite to that of the inducing pole.**

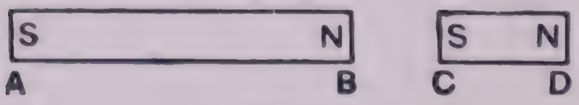


Fig. 16.

The experiment also indicates why a magnet attracts neutral, *i.e.* unmagnetised, iron. When the magnet pole is brought near the iron, the latter is magnetised by induction, and the result is attraction between the magnet pole and the unlike pole induced in the part of the iron nearest to it. Thus *induction always precedes the attraction between a magnet and a (previously) unmagnetised body.*

**26. Magnetic Field. Magnetic Lines of Force.—The magnetic field of a magnet is the whole space round about the magnet where its influence is felt,** *i.e.* **the whole space in which magnetic material will experience magnetic force due to the magnet.**

Consider a point $P$ (Fig. 17) in the field of the bar magnet $NS$ and imagine an isolated north pole perfectly free to move to be placed at $P$. It will be attracted by $S$ and repelled by $N$. If $PQ$ and $PR$ represent these two forces, then $PT$, the diagonal of the parallelogram $PRTQ$, will represent the resultant force on the north pole at $P$. The pole will be urged in the direction of the resultant force $PT$, but as it changes its position the direction of the resultant force changes, and the direction of motion changes also. Thus the free north pole will be urged along a curve starting from the north end $N$ and finishing at the south end $S$ of the magnet. *The line (or curve) along which an isolated north pole would travel if free to move in a magnetic field is called a magnetic line of force.*

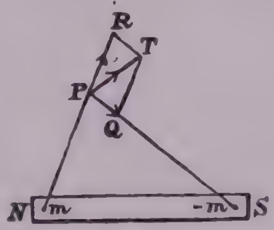


Fig. 17.

In practice it is impossible to obtain a single pole—there are always at least two poles in a magnet—hence consider a small pivoted magnet, like a watch chain compass, to be placed at $P$. Its north pole tends to move along a line of force, and its south pole tends to move the other way along a line of force. The net result is that the compass sets in a definite direction, and if it is small, *this direction is a tangent to the line of force through the small compass.* Clearly if the lines of magnetic force in a magnetic field are straight, the compass sets along the lines. Further, if the needle is a very small one or if it is a piece of iron filing magnetised by induction, *we may assume that it lies on and along the line of force whether straight or curved,* and this furnishes a means of mapping out the lines in any particular case (see below).

To summarise :—**A line of magnetic force is a line along which an isolated north pole would travel if free to move in a magnetic field, and it is such that the tangent to it at any point gives the direction of the resultant force at that point.**

**27. Different Cases of Magnetic Lines of Force.**—Let a sheet of cardboard be placed over a magnet and let iron filings be dusted over it. As the filings fall on the card they come under the inductive influence of the magnet, and each, becoming a magnet, sets itself in the direction of the magnetic force at the point where it is placed. Thus on gently tapping the card the filings arrange themselves in continuous curves and roughly indicate the magnetic lines of force in the plane of the card. Figs. 18, 19, 20 indicate the results with different arrangements of magnets. The following points should be noted :—

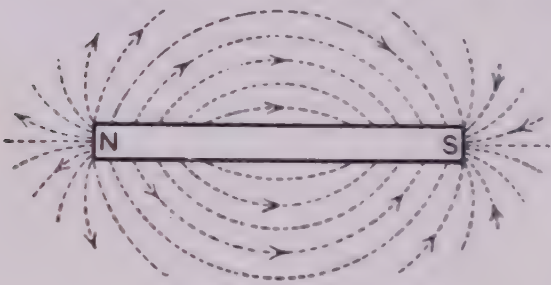


Fig. 18.

(1) The positive direction of a line is the direction in which a free *north* pole would be urged along it : thus the positive direction is *from N to S* in the figures and is indicated by arrows.

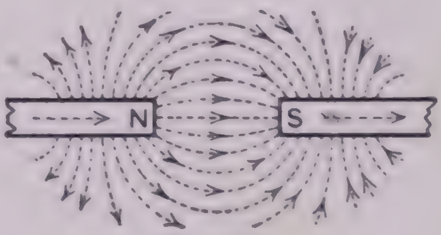


Fig. 19.

(2) All the curves show that lines from a north pole curve round and enter a south pole (*e.g.* Figs. 18, 19), but lines associated with two like poles turn away from each other (*e.g.* Fig. 20). Faraday put forward an explanation of attraction and repulsion which, in homely language, may be put thus : "Lines

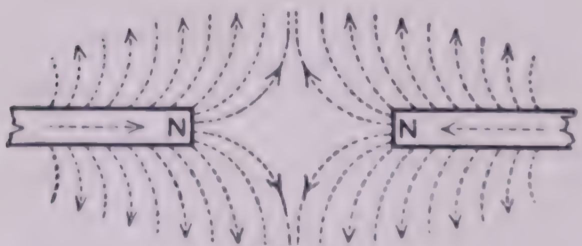


Fig. 20.

tend to contract in the direction of their length whilst lines proceeding in the same direction tend to repel each other." Thus the contraction of the lines in the direction of their length will account for the attraction between unlike poles (*e.g.* examine Fig. 19,), whilst lateral repulsion will account for the repulsion between like poles (*e.g.* examine Fig. 20).

(3) The field of a magnet exists on all sides of it and is not confined to one plane as the figures must be.

(4) In the field the magnetic lines run, as has been stated, from N. to S., but the lines entering the south pole are really continued through the magnet itself, finally reaching the north pole from which we supposed them starting: thus *each line forms a closed curve* or circuit. There is a distinction, however, between these internal lines and the lines of force in the field outside, but we need not worry the student about this at present.

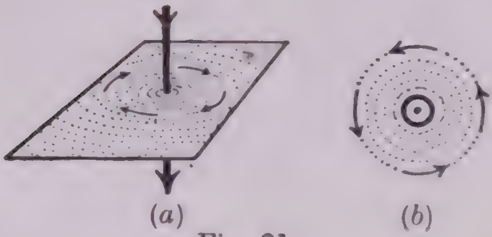
**28. Magnetic Field and Magnetic Lines due to a Current in a Straight Wire.**—We have seen that if a wire $AB$ has a potential difference between the ends $A$ and $B$—say $A$ at a higher potential than $B$—electricity will flow from $A$ to $B$ as long as that potential difference is maintained, the flow being referred to as a current of electricity in the wire. For the present we will assume that the student has some means of getting such a current (*e.g.* a battery) and that he knows which way the current is passing in the wire. Incidentally he must remember that the *electronic current*—the actual movement of electrons —is opposite to the usually accepted *conventional current*, *i.e.* in the case referred to the electrons "flow" from the low potential $B$ to the high potential $A$ of the wire. In what follows we shall assume the conventional current, *i.e.* the current from $A$ to $B$—from the high to the low potential—unless the contrary is specially mentioned.

It was soon discovered that **a conductor which is carrying a current has a magnetic field surrounding it.** This can be verified by a few simple experiments.

(1) Bore a hole in a piece of cardboard, fix it in a horizontal position, pass a wire vertically through it, and let a strong current flow through the wire. Sprinkle iron filings on the cardboard and gently tap the latter. The filings arrange

themselves in concentric circles round the wire as their common centre ; these indicate the lines of force in the magnetic field due to the current (Fig. 21).

(2) Arrange that the current is flowing *down* the wire. Move a small compass needle round the wire and note in which direction the north pole points. In this case it will be found that the north pole points as indicated by the arrows in Fig. 21 (*a*), *i.e.* the positive direction of the lines of force is *clockwise.* Repeat with the current flowing *up* the wire : the north pole will move in the opposite direction, *i.e.* the positive direction of the lines is *counter-clockwise* (Fig. 21 (*b*) ).


(*a*) (*b*)
Fig. 21.

(3) Place a compass needle on the table, and hold a wire *above* and parallel to it, as shown in Fig. 22. Pass a current through the wire (*a*) from south to north, (*b*) from north to south, and note in which direction the north pole of the needle is deflected ; it will be found that in (*a*) the north pole of the needle moves towards the *west*, and in (*b*) towards the *east*. Hold the wire *below* the needle and again pass a current (*c*) from south to north, (*d*) from north to south ; it will be found that in (*c*) the north pole of the needle is deflected towards the *east*, and in (*d*) towards the *west*.

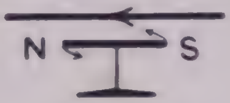


Fig. 22.

The results of the above need not be committed to memory : they can be obtained from the following rule, which the student should verify from the experiment :—*Imagine a man swimming in the circuit in the direction of the current and with his face towards the needle : the north pole of the needle will be deflected towards his left hand.*

As already emphasised, on the electron theory a current in a wire is a flow of (negative) electrons in the wire, and this flow will be in the opposite direction to the conventional current considered above, *i.e.* the electrons go from what we have called the low to what we have called the high potential. On this theory, the preceding rule would evidently read :—

"Suppose a man swimming with the flow of electrons and facing the needle: the north pole will be deflected *towards his right.*"

**29. Magnetic Field and Magnetic Lines due to a Current in a Circular Coil of Wire.**—This also can be investigated by a simple experiment:—

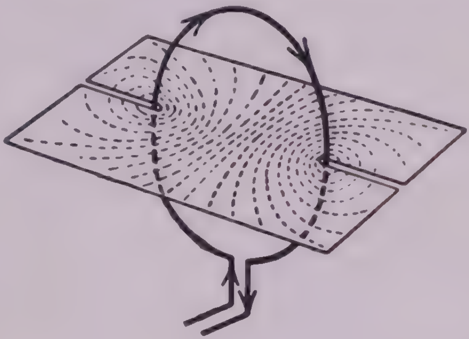


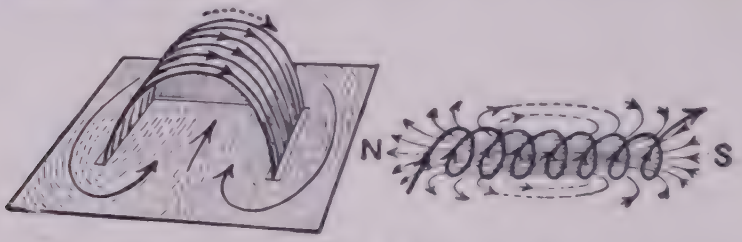
Fig. 23.

Fix a coil of wire in a card as shown in Fig. 23. Set the coil with its plane pointing north and south. Pass the current and show the lines of force by iron filings. Place a compass needle at the centre of the coil and note which way the north pole points. This gives the direction of the magnetic field at the centre: in Fig. 23 it will be away from the observer. Reverse the current and repeat. The lines will be the same as before, but the direction of the field will be towards the observer.

In the above, the direction of the field at the centre of the circular coil may be obtained from the rule already given in Art. 28, but the following is also convenient:—*Looking at the face of the coil, if the current is clockwise, the positive direction of the lines inside the coil is away from the observer; if the current is counter-clockwise, the positive direction is towards the observer.*

**30. Magnetic Field and Magnetic Lines due to a Current in a Solenoid.**—Make a solenoid, *i.e.* a long coil consisting of many turns of insulated copper wire, and fix as shown in Fig. 24 (*a*). Pass a current and determine the lines by filings and the direction of the magnetic field by a compass. Reverse the current and repeat.

It will be found that the magnetic field of a solenoid resembles the magnetic field of a bar magnet. The lines of force leave one end of the solenoid, pass through the outside field and enter the other end (completing their circuit through the solenoid itself). In fact, the solenoid in Fig. 24 (*a*) corresponds to a bar magnet, the near end, *at which the current is circulating clockwise*, corresponding to the *south pole*, and the remote end, *where the current is circulating counter-clockwise*, corresponding to the *north pole*. Fig. 24 (*b*) will serve to emphasise these facts.



(*a*) Fig. 24. (*b*)

From the results of the above experiments the following rules for the polarity of a current-carrying solenoid are deduced :—

(1) *Imagine a man swimming in the circuit in the direction of the current and with his face towards the inside of the solenoid : his left hand will be towards the north end of the solenoid.*

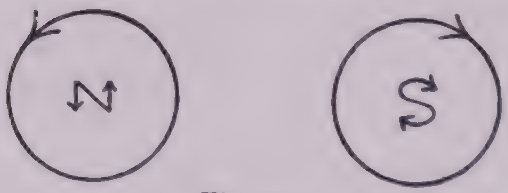


Fig. 25.

(2) *Look at the end of the solenoid ; if the current is* **counter-clockwise** *that end is a* **north,** *if it is* **clockwise** *that end is a* **south.**

The last rule is important, and the drawing of Fig. 25 will assist the student to remember it. If a bar of iron be placed inside a solenoid it is converted into a magnet when the current passes, the polarity of the iron being the same as that of the solenoid : such magnets are termed **electro-magnets**. Typical electro-magnets are shown in Fig. 26.

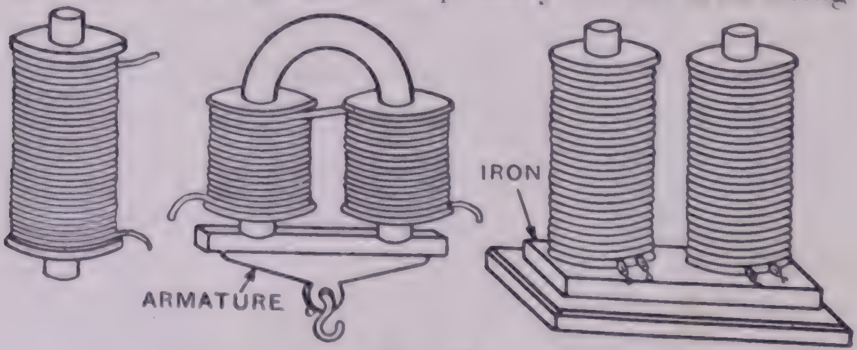


Fig. 26.

**31. Magnetic Field and Magnetic Lines due to two Parallel Currents.**—If two flat spirals of wire be each suspended by a thread, so that they hang parallel, and a current be passed in each, it will be found that *they attract each other if the currents go in the same direction, and repel each other if the currents go in opposite directions.* Remembering that the currents make each spiral practically a magnet with one face a north pole and the other a south, the above is just what would be expected.

Ampère proved the following laws in connection with straight circuits :—

(1) *Two* PARALLEL *currents attract or repel one another according as they flow in the same or in opposite directions.*

(2) *Two* NON-PARALLEL *currents attract one another if both approach or both recede from the point of meeting of their directions, while they repel one another if one approaches and the other recedes from that point.*

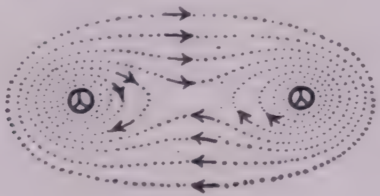


Fig. 27.

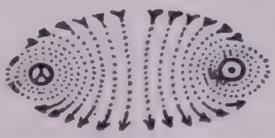


Fig. 28.

Fig. 27 shows the magnetic lines of force in the case of two parallel wires when they carry equal currents in the same direction, and Fig. 28 when they carry equal currents in opposite directions. It is clear from these that there will be attraction in the first case and repulsion in the second, for lines tend to contract in the direction of their length (thus tending to bring the wires together in Fig. 27) whilst lines proceeding in the same direction repel (thus tending to move the wires apart in Fig. 28).

**32. Magnetic Strains in the Aether.**—The question again arises, what are these magnetic lines, which are not visible and which cannot be physically laid hold of ? If we fix our attention on the suspended magnet of Art. 23, to which another magnet is brought near, we note that the suspended one begins to move when the other is still a distance away. Some force is causing it to move and there must be some medium conveying the force. It has been mentioned that if we wish to move a body we might do it by fastening a rope to it and pulling, or we might do it by pushing it with a stick, but there must always be a medium of some sort connecting the force applied and the body moved : and moreover, the rope or the stick or the medium transmitting the force is *strained*.

Now in the case of the magnets referred to, the experiment still works if the magnets are in a vacuum, so the medium which transmits the force is certainly not the air. It must in fact be the aether of Art. 20, that substance which surrounds, permeates, and fills all matter, however apparently "solid," and all space. And the aether conveys the force from one magnet to the other because it is strained. The lines of force we have been dealing with are lines of strain in the aether. This particular aether strain has no effect on charged bodies, but it does affect compasses, magnets, and other magnetic substances, and so it is spoken of as a **magnetic strain in the aether,** and the lines which indicate the direction of the strain are spoken of as **magnetic strain lines in the aether.**

**33. Electric Aether Strains and Magnetic Aether Strains in Wireless.**—In the last chapter we saw that if two neighbouring bodies are charged, one positively the other negatively (Fig. 8) the aether between them is *electrically strained*, and lines of electric force pass from one body to the other : these lines are really *electric strain lines in the aether*. Electric aether strains are thus associated with electricity *at rest*.

In the present chapter we have seen that when a current flows in a wire the aether round about the wire is *magnetically strained*, and lines of magnetic force form circles round about the wire : these are really *magnetic strain lines in the aether*. Magnetic aether strains are thus associated with electricity *in motion*.

Now here is a case that occurs in wireless. In Fig. 29 (*a*) *A* is a body positively charged and *B* is another negatively charged. The aether between them is electrically strained, the electric strain lines being as indicated.

Suppose now that *A* and *B* become discharged by a spark passing from *A* to *B* (Fig. 29 (*b*)). This rush of electricity is of course a current. The aether round about the path of the spark is *magnetically strained*, the magnetic strain lines being as indicated.

Again, a glance at Figs. 29 (*a*), 29 (*b*) will show that the magnetic lines of strain are at right angles to the electric lines of strain.

Now suppose we arrange matters so that these charges and discharges occur repeatedly one after the other. This will give rise to electric and magnetic strains (at right angles to each other) occurring repeatedly one after the other, and, as the student will see later, when this happens a wave motion is set up in the aether and travels outwards with the velocity of light (186,000 miles per second). With suitably constructed apparatus these are "wireless" waves, the starting point of which is therefore these electric and magnetic aether strains at right angles. Hence the importance to the wireless student of a thorough grasp of these fundamentals. All this, however, will be dealt with in detail in subsequent chapters.

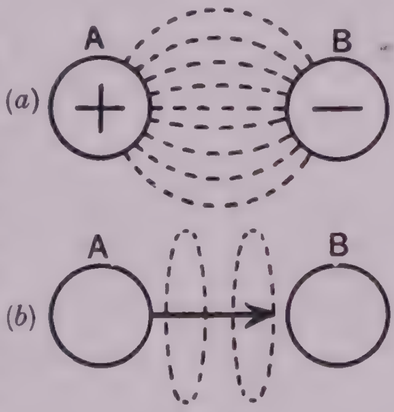


Fig. 29.

# CHAPTER III.

## SOME UNITS AND SIMPLE ELECTRICAL THEORY.

**34. Introduction.**—In the present chapter a very brief account is given of some important quantities met with in all phases of electrical work—pure electrical science, electrical engineering, telegraphy and telephony, wireless—and the units in terms of which these quantities are measured. No attempt is made to go fully into details, for such are scarcely necessary at this stage of the reader's progress, and the treatment is designedly simple. On the other hand, the subjects dealt with are of the *greatest* importance, and the little that is given should be thoroughly mastered, for frequently wireless enthusiasts are "held up" owing to their lack of knowledge in this direction. For fuller details reference should be made to some work on electrical theory.

**35. Effects of an Electric Current.**—In Art. 15 it has been explained that in order to secure a continual flow of electricity from one point to another some conducting path must be provided between them, and means must be devised for maintaining the two points at different potentials, in which case electricity will continue to flow from the higher to the lower potential (the electrons, of course, go the other way). With the various methods whereby a P.D. can be kept up at the ends of a conductor, the reader will become acquainted later. In fact it is done by means of batteries and dynamos, and in these days of "wireless" and "electricity" generally, most students know something about these. In all cases the conductor acquires certain new properties due to this agent "flowing" along it, and technically, as already mentioned, we refer to it as a "current" of electricity in the conductor.

The existence of a current of electricity is known by various effects which it produces, *e.g.* :—

(1) A compass needle suitably placed near the wire is deflected, and if the wire be coiled round a bar of soft iron the latter is converted into a magnet; these are known as the *magnetic effects* of the current. (Some of these effects have been dealt with in the preceding chapter.)

(2) If the wire conveying the current be cut, the ends soldered to two suitable metal plates, and these placed some short distance apart in various liquids, the majority of the latter are decomposed, one of the products of the decomposition appearing at one plate, and another at the second plate; these are known as the *chemical effects* of the current.

(3) The conductor through which the current flows becomes heated: this is referred to as the *heating effect* of the current.

**36. Steady Flow of Water through a Pipe.**—Consider a pipe $AB$, through which water is flowing steadily from $A$ to $B$. Some idea of the strength of this water current may be obtained from a statement of the quantity of water entering $A$, leaving $B$, or passing any section of the pipe in a definite time, say one second; in short, *the strength of the current may conveniently be defined as the rate of flow of water through the pipe.* Accepting, then, this definition, *the total quantity flowing past any section in a given time will be obtained by multiplying the current strength by the time in seconds.* Further, when the pipe is quite full, the quantity entering $A$ per second must be equal to the quantity leaving $B$ or passing any section of the pipe in that time, however uneven the bore may be; that is, *the current strength is the same at all parts of the pipe.*

**37. Current Strength and Quantity of Electricity.**—The above elementary ideas have their electrical analogies. **Current strength** is defined as **the quantity of electricity passing any section of the conductor per second,** *i.e.* as **the rate of flow of electricity in the circuit,** and *the total quantity which passes in a stated period is given by the product of the current strength and the time in seconds*; stated algebraically, if $I$ denotes the current strength and $Q$ the quantity transferred in $t$ seconds, $Q = It$. Further, *the current strength is the same at all parts of* *a simple conductor*, but, as we have seen, there is a fall of potential in the direction in which the current is flowing; this latter statement is evident from the fact that if electricity is flowing along a simple conductor past the points $A$, $B$, $C$, etc., then $A$ must be at a higher potential than $B$, $B$ at a higher potential than $C$, and so on. We are, of course, assuming the conventional current.

**38. The Ampere as the Unit of Current Strength.**—We have referred to the fact that certain liquids are "decomposed" by a current of electricity. The process is termed **electrolysis,** the liquid is called the **electrolyte,** and the containing vessel the **voltameter.** The metal plates by which the current enters and leaves the liquid are termed the **electrodes**; that by which it enters is the **anode,** that by which it leaves is the **kathode.** The constituents which are liberated at the electrodes are called the **ions.**

A typical example is afforded by a solution of copper sulphate ($CuSO_4$). If this be placed in a voltameter fitted with platinum electrodes and a current be passed, it will be found that copper is deposited in a fine uniform layer on the kathode whilst oxygen appears at the anode, the actions being expressed by the equations

$$\underset{\text{Copper Sulphate}}{CuSO_4} = \underset{\text{Copper}}{Cu} + \underset{\text{Sulphion}}{SO_4}$$

$$\underset{\text{Sulphion}}{SO_4} + \underset{\text{Water}}{H_2O} = \underset{\text{Oxygen}}{O} + \underset{\text{Sulphuric Acid}}{H_2SO_4}$$

A solution of silver nitrate furnishes another example: in this case the important point to note is that silver is deposited on the kathode.

Now the whole question of units in electricity (for measuring and calculation purposes) is very interesting but somewhat complicated, and details are really not required by the reader at this stage. Suffice it to say that a certain unit of current strength was decided upon—a unit based on strict scientific principles. Later this was found to be too large for practical purposes, and a unit $\frac{1}{10}$ of this was taken as the practical unit of current strength; this unit was named the **ampere.** If a current of one ampere be passed through a solution of silver nitrate, it will deposit silver on the kathode at the rate of ·001118 gramme per second, and this fact is used by the Standards Committee of the Board of Trade in defining the ampere. Hence :—

The unit of *current strength* is the *ampere* : **the (international) ampere is that unvarying current which, when passed through a solution of silver nitrate in water, deposits silver at the rate of ·001118 gramme per second.**

$$1 \text{ milliampere} = \tfrac{1}{1000} \text{ ampere.}$$

In practice the strength of the current in a circuit is measured by specially constructed instruments called *galvanometers* or by commercial forms called *ammeters*.

**39. The Coulomb and Ampere-hour as Units of Quantity.**—Since Quantity = Current Strength × Time in Seconds, it follows that unit current flowing for one second will mean that unit quantity has passed, whilst a current of strength, say 5 units, flowing for say 20 seconds, will mean that 100 quantity units have passed, and so on. The name given to the practical unit of quantity is the **coulomb**. Hence :—

The unit of *quantity* is the *coulomb* : **the (international) coulomb is the quantity of electricity conveyed by a current of one ampere in one second.**

$$\text{Coulombs} = \text{Amperes} \times \text{Time in Seconds.}$$

Again since one (international) ampere in one second deposits ·001118 gramme of silver, and one ampere for one second means one coulomb, **the (international) coulomb is that quantity of electricity which liberates ·001118 gramme of silver from a solution of silver nitrate.**

Another practical quantity unit termed the **ampere-hour** is employed. **An ampere-hour is the quantity of electricity conveyed by a steady current of one ampere flowing for one hour.** But one ampere in one hour will transfer 60 × 60, *i.e.* 3600 coulombs ; hence 1 ampere-hour = 3600 coulombs.

$$\text{Ampere-hours} = \text{Amperes} \times \text{Time in Hours.}$$

**40. The Ohm as the Unit of Resistance.**—Resistance may be defined in a general way as *that property of a body which opposes the flow of electricity through it* ; good conductors have small resistance, insulators have enormous resistance. With a given potential difference (P.D.), the less the resistance the greater will be the current, and *vice versa* ; it is from this that a precise definition of resistance is obtained.

Consider two points *A* and *B* in a conductor, between which there is no dynamo or battery, and imagine a steady direct P.D. to exist between the two points ; a certain steady direct current will be flowing between them. If, now, the P.D. be altered in magnitude the strength of the current will also be changed, but experimentally it can be proved that *if the temperature of the conductor be kept constant, the ratio of the P.D. to the current is constant* ; this constant is called the **resistance** of the part *AB* of the conductor ; stated algebraically :—

$$\frac{\text{Potential Difference}}{\text{Current}} = \text{a constant} = \text{Resistance.}$$

The unit in terms of which the potential difference is to be measured is dealt with in Art. 41.

Now here again a certain scientific unit of resistance exists which, however, is too small for practical purposes, and another unit is employed which is really one thousand million times as big : this unit is called the **ohm**, and for the student at this stage the following legal definition is perhaps the simplest.

The unit of *resistance* is the *ohm* : **the (international) ohm is the resistance of a column of mercury 106·3 centimetres long, 1 square millimetre in cross section (mass 14·4521 grammes) at the temperature of melting ice (0° C.).**

1 megohm = 1,000,000 ohms : 1 microhm = $\frac{1}{1000000}$ ohm.

In practice the resistance of a circuit is measured by specially designed instruments known as *ohmmeters*, *meggers*, etc. Various laboratory instruments for more accurate measurements are also employed.

### 41. The Volt as the Unit of Potential Difference (P.D.) and Electro-motive Force (E.M.F.).

—From Art. 40 we have :—

$$\frac{\text{Potential Difference}}{\text{Current}} = \text{Resistance.}$$

$$\therefore \text{ Potential Difference} = \text{Current} \times \text{Resistance.}$$

Now it is clear that if the resistance between the two points $A$ and $B$ (Art. 40) be unity and the current flowing be unity, the potential difference between $A$ and $B$ must be unity. The name given to the practical unit of potential difference or pressure is the **volt**. Hence :—

The unit of *P.D.* or *pressure* is the *volt*: **the volt is that potential difference or electrical pressure which, if steadily applied to a conductor whose resistance is one ohm, will produce in it a steady current of one ampere.**

$$1 \text{ microvolt} = \tfrac{1}{1000000} \text{ volt.}$$

As in the case of current strength and resistance, a certain unit of pressure exists which is based on strict scientific principles, but this unit is too small for most practical purposes : the volt is one hundred million times as big.

When the poles of a battery, say, are not connected, *i.e.* when the battery is on "open circuit" as it is called, the positive pole is at a higher potential than the negative pole, as will be explained later. This *potential difference on open circuit* is a characteristic of the battery (depending on the materials used in making it) and is called the **electro-motive force** (E.M.F.) of the battery. It is of course measured in volts.

In practice the pressure in a circuit is measured by an instrument called a *voltmeter*. Various laboratory instruments for very accurate measurements are also employed.

**42. Ohm's Law.**—This important law has already been given in connection with the definition of resistance in Art. 40 ; briefly it may be stated thus :—**When the temperature of a conductor is kept constant, the ratio of the steady direct P.D. between any two points (no generator of E.M.F. being between them) to the resulting steady direct current is constant.** In symbols the law may be expressed by the equation :—

$$\frac{E}{I} = \text{ a constant} = R.$$

where $E$ is the P.D., $I$ the current, and $R$ a constant, the value of which is termed the resistance of the part of the conductor considered. For calculations it is convenient to remember three forms of the equation; thus from the form :—

$$\frac{E}{I} = R, \text{ i.e. } \frac{\text{Potential Difference}}{\text{Current}} = \text{Resistance}$$

we obtain

$$E = IR, \text{ i.e. Potential Difference} = \text{Current} \times \text{Resistance},$$

and $$I = \frac{E}{R} \text{ i.e. Current} = \frac{\text{Potential Difference}}{\text{Resistance}}.$$

The last form is the one most commonly used. Expressed in terms of the various units it is written :—

$$\text{Current in amperes} = \frac{\text{Potential Difference or Pressure in volts}}{\text{Resistance in ohms}}$$

**43. Simple Calculations on Ohm's Law.**—The following simple examples will help to "fix" the preceding important law.

**Examples.**—(1) *An* 11 *volt battery, whose resistance is* 50 *ohms, is used to work a telegraph line* 8 *miles long, the resistance of the line wire being* 10 *ohms per mile. Find the strength of the current in milliamperes, the resistance of the instrument being* 101 *ohms.*

$$\text{I} = \frac{E}{R} = \frac{11}{50 + (10 \times 8) + 101} = \frac{1}{21} \text{ ampere}$$

$$\therefore \text{ Current in milliamperes} = \tfrac{1}{21} \times 1000 = 47{\cdot}6.$$

(2) *What pressure will be required to send a current of* 20 *amperes through a resistance of* 5 *ohms? A dynamo of E.M.F.* 110 *volts sends a current of* 11 *amperes round a circuit: what is the total resistance of the circuit?*

(*a*) **Pressure required** $= E = IR = 20 \times 5 =$ **100 volts.**

(*b*) **Total resistance** $= R = \frac{E}{I} = \frac{110}{11} =$ **10 ohms.**

**44. Joining Conductors in Series.**—If several resistances $r_1, r_2, r_3,$ (Fig. 30) be joined in *series* (*i.e,* end to end) the total resistance $R$ is clearly their sum, *i.e.*

$$R = r_1 + r_2 + r_3.$$

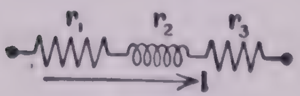


Fig. 30.

It must be remembered that the current in a simple series circuit like this is the same at all parts, however the parts differ in resistance. Further, it will be noted that this rule was used in the examples of Art. 43.

**45. Joining Conductors in Parallel.**—If several resistances $r_1$, $r_2$, $r_3$, be joined in *parallel* as indicated in Fig. 31, it can be easily proved that the total resistance $R$ is obtained thus :—

$$\frac{1}{R}=\frac{1}{r_1}+\frac{1}{r_2}+\frac{1}{r_3}.$$

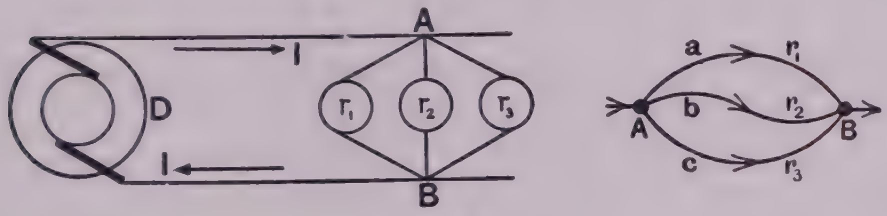


Fig. 31.

For example, if three resistances of 2, 3, and 4 ohms respectively be put in parallel, we have $\frac{1}{R}=\frac{1}{2}+\frac{1}{3}+\frac{1}{4}=\frac{13}{12}$, *i.e.* $R=\frac{12}{13}$ ohm : *the total resistance is thus less than the resistance of the least of them.* Similarly, *if the resistance of each of them is, say,* 6 *ohms, the total resistance is* 2 *ohms*, i.e. *one third of the resistance of one of them.* This effect of joining conductors in parallel should be particularly noted.

The proof of the formula above may be briefly indicated in passing. If $E$ be the P.D. between $A$ and $B$ :—

Total current = Current in $a$ + current in $b$ + current in $c$.

$$\therefore \frac{E}{R}=\frac{E}{r_1}+\frac{E}{r_2}+\frac{E}{r_3}, \text{ i.e. } \frac{1}{R}=\frac{1}{r_1}+\frac{1}{r_2}+\frac{1}{r_3}.$$

**46. Division of a Current amongst Conductors in Parallel.**—Whilst the current is the same at all parts of a simple (series) circuit, however the parts differ in resistance, in a parallel arrangement *the current divides inversely as the resistances* : thus if a total current of 9 amperes passes through two wires $A$ and $B$ in parallel, $A$ having a resistance of 1 ohm and $B$ a resistance of 2 ohms, it will be found that 6 amperes flow through $A$ and 3 amperes flow through $B$. The following example will illustrate this point further :—

**Example.**—*Three wires, A, B, and C, of 2, 4, and 6 ohms resistance respectively, are arranged in parallel, and the total current passing is 22 amperes. Find the joint resistance and the current in each wire.*

If $R$ = joint resistance :—

$$\frac{1}{R} = \frac{1}{2} + \frac{1}{4} + \frac{1}{6} = \frac{6+3+2}{12} = \frac{11}{12}, \quad \therefore R = \frac{12}{11} = 1\tfrac{1}{11} \text{ ohms.}$$

Again:—

Current in A = $\frac{6}{11}$ of 22 amperes = 12 amperes
" " B = $\frac{3}{11}$ of 22 " = 6 "
" " C = $\frac{2}{11}$ of 22 " = 4 "

**47. Laws of Resistance.**—The chief laws of resistance may be summarised as follows :—

(1) *The resistance of a conductor is directly proportional to its length* : 1 yard of copper wire of 20 B.W.G. (Birmingham Wire Gauge) has a resistance of ·02 ohm ; hence lengths of ·5 yard and 2 yards will have resistances of ·01 ohm and ·04 ohm respectively.

(2) *The resistance of a conductor is inversely proportional to its cross-sectional area* : thus if one wire has twice the area of cross-section of another wire of the same material, and equal lengths be taken, *the thick one will have half the resistance of the thin one.*

(3) *The resistance of a conductor depends on the material* : thus a piece of platinum has nearly six times the resistance of a piece of copper of the same dimensions. In lists giving the resistances of different materials it is usual to state what is called the **specific resistance** or **resistivity**, *i.e.* the resistance of a cube of the material of 1 inch side (inch cube), or of a cube of 1 centimetre side (cm. cube).

Again, the thickness of a wire is often settled by a number termed its "gauge"; thus 20 B.W.G. (Birmingham Wire Gauge) refers to a wire ·035 inch in diameter ; 16 S.W.G. (Standard Wire Gauge) is a wire of ·064 inch diameter. The larger the "gauge" number the smaller is the diameter. The French Gauge is an exception to this rule.

Conductors are often formed of stranded wire on account of the greater pliability and less liability to complete fracture than in the case of solid wires ; thus 7/16 cable refers to one whose conductor is composed of seven-stranded wires, each wire of 16 gauge.

The resistance of an alloy (mixture of metals) is always greater than that of the substances composing it.

**48. Effect of Heat on Resistance.**—Metals *increase* in resistance when heated and decrease in resistance when cooled.

Alloys also *increase* in resistance when heated, but not to the extent that pure metals do. The high resistance and small variation of resistance with temperature in the case of alloys lead to their extensive use in the construction of standard resistances for testing purposes.

Carbon, electrolytes, and insulators all *decrease* in resistance when heated. It should be particularly noted that insulators become *worse insulators* when heated, and some, if strongly heated, may become fairly good conductors.

**49. The Farad as the Unit of Capacity.**—We have seen that if a charge of electricity be given to a conductor the potential of the conductor is altered. Now the **electrical capacity** of a conductor may be defined as *the ratio of the charge given to the conductor to the potential produced in the conductor by that charge.* Thus if a charge $Q$ raises the potential of a conductor to $V$, then the capacity ($C$) of the conductor is given by the expression :—

$$\text{Capacity} = \frac{\text{Quantity}}{\text{Potential}}, \ \textit{i.e.}\ C = \frac{Q}{V}.$$

Another way of putting it is to say that **the capacity of a conductor is measured by the quantity of electricity necessary to raise the conductor to unit potential.** Thus if a charge of 20 coulombs of electricity raises the potential of a conductor to five volts, the capacity of the conductor is $\frac{20}{5} = 4$ units (of capacity) *i.e.* the conductor requires 4 coulombs to raise it to one volt potential.

The unit of *capacity* is the *farad* : **a conductor has a capacity of one farad if a charge of one coulomb raises its potential by one volt.**

$$1 \text{ microfarad} = \frac{1}{1000000} \text{ farad.}$$

1 micro-microfarad = one millionth of one millionth of a farad.

**50. Electrical Energy.**—Whenever a P.D. exists between two points in an electric circuit an *energy transformation* occurs between them. When a current flows along a copper wire, energy is subtracted from the electric circuit, appearing as heat in the wire; when a current flows through the filament of a glow-lamp, energy is again subtracted from the electric circuit, part appearing as heat in the filament, part being dissipated as heat communicated to the air and bodies near, and part being utilised in setting up the aether vibrations which constitute light. Passing a current through a voltameter results in the transformation of electrical energy into heat energy and into the potential energy of chemical separation, whilst passing it through a motor gives a transformation into heat and mechanical work. In all cases the electrical energy which disappears is equivalent to the new forms into which it is transformed.

Now in electrical engineering the unit of electrical energy or electrical work is called a **watt-hour**. If the pressure at the terminals of an electric lamp, say, be $E$ volts and the current passing be $I$ amperes, and if this current flows for $T$ hours, then the total electrical energy in watt-hours absorbed by that lamp in that time is calculated thus :—

$$\text{Energy in Watt-hours} = \text{Volts} \times \text{Amperes} \times \text{Hours},$$
$$\textit{i.e.}\ \text{Watt-hours} = EIT.$$

Clearly if $E$, $I$, and $T$ be each unity the energy in watt-hours is unity; hence **if the pressure between two points is one volt, and one ampere flows for one hour, the electrical energy taken by the circuit between the points is one watt-hour.**

A larger unit of electrical energy is chosen by the Board of Trade. It is equal to 1000 watt-hours, and is called a **Board of Trade Unit.** The number of B.O.T. units of energy taken by the above lamp is therefore calculated thus :—

$$\text{No. of B.O.T. units} = \frac{\text{Volts} \times \text{Amperes} \times \text{Hours}}{1000} = \frac{EIT}{1000}.$$

The electrical engineer's B.O.T. unit of energy is over two and a half million foot-pounds—the foot pound being the mechanical engineer's unit of energy.

**51. Electrical Power.**—Power is defined as the *rate at which work is being done, i.e.* it is measured by the work done per second. Now in electrical engineering, the unit of electrical power is called a **watt**. If the pressure at the terminals of an electric lamp, say, be $E$ volts and the current passing be $I$ amperes, the power absorbed by the lamp is calculated thus :—

$$\text{Power in Watts} = \text{Volts} \times \text{Amperes},$$
$$\textit{i.e.}\ \text{Watts} = EI.$$

Clearly if $E$ and $I$ be unity the power in watts is unity; hence **if the pressure between two points is one volt, and one ampere is flowing, the power in the circuit is one watt.**

A larger unit of power is the **kilowatt**, which is equal to 1000 watts : hence :—

$$\text{No. of Kilowatts} = \frac{\text{Volts} \times \text{Amperes}}{1000} = \frac{EI}{1000}.$$

The power of an electrical machine is generally expressed in kilowatts : thus a dynamo capable of supplying 40 amperes at 2000 volts has a power of 2000 × 40, *i.e.* 80,000 watts or 80 kilowatts, and is spoken of as an 80 unit machine. A kilowatt is roughly equal to about $1\frac{1}{3}$ horse-power, the latter being the mechanical engineer's unit of power.

# CHAPTER IV.

## BATTERIES.

**52. A Simple Cell.**—(1) If a plate of common zinc (Zn) be placed in dilute sulphuric acid ($H_2SO_4$) a violent action ensues, the zinc being eaten away, zinc sulphate ($ZnSO_4$) formed, and hydrogen gas (H) evolved ; the chemical action is represented by the equation :—

$$Zn + H_2SO_4 = ZnSO_4 + H_2.$$

On the whole *energy is liberated during the process*, appearing as heat in the solution .

(2) If the zinc be now amalgamated (*i.e.* its surface coated with mercury) and replaced in the dilute acid, no action will be observed.

(3) If a plate of copper be put in the acid, again no action will be noticed.

(4) If the copper and amalgamated zinc be placed side by side but without contact in the acid, no action will be observed ; but if they be connected outside by a wire (Fig. 32), it will be found that (*a*) the zinc is eaten away and zinc sulphate formed, (*b*) hydrogen gas appears *at the copper plate*, and (*c*) *a current of electricity flows in the circuit in the direction copper to zinc in the connecting wire, zinc to copper in the liquid.* (Of course electrons go the other way).

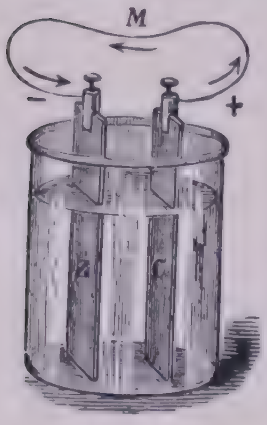


Fig. 32.

Such an arrangement is known as a **simple, galvanic,** or **voltaic cell.** The copper plate is at a higher potential than the zinc, and is called the *high potential plate*, the portion of it outside the acid being termed the *positive pole* of the cell ; the zinc is known as the *low potential plate,* the portion of it outside the acid being termed the *negative pole.* In the outside circuit the current flows *naturally* from the high-potential copper to the low-potential zinc; inside the cell the energy of the chemical action previously referred to is utilised in *forcing* the electricity from the low to the high potential. The chemical action is, in fact, analogous to that of a pump lifting water from a lower to a higher level, from which position the water would naturally run down again, doing work in virtue of the energy conferred upon it. Thus in the cell the consumption of the zinc really furnishes the energy which maintains the current in the circuit.

It frequently happens that a single cell of any kind is insufficient to do what we want, and we then use a combination of several cells: such a combination is called a **battery**.

**53. Local Action.**—Common zinc contains many impurities, such as iron, lead, arsenic, etc.; these, together with the zinc, being in contact with the acid give rise to a number of local currents all over the surface of the plate, the result being that the latter is consumed without any advantage being gained therefrom. This, termed **local action**, is prevented by *amalgamating* the plate, *i.e.* coating its surface with mercury. The latter dissolves the zinc, forming a uniformly soft amalgam, which covers up the impurities; as the zinc is consumed the impurities fall to the bottom of the cell. Local currents between portions of the plate differing in hardness are also prevented by this device.

**54. Polarisation.**—In Art. 52 it was noted that hydrogen bubbles appeared *at the copper plate* when the poles of the cell were connected, and this is readily explained by the fact that positive hydrogen ions *do* travel through the liquid towards the copper plate (and negative ions travel the other way through the liquid towards the zinc plate). This deposition of hydrogen on the copper is called **polarisation**: it weakens the current and spoils the cell in two ways:—(1) the gas has a large resistance, (2) a **back E.M.F.** is set up which, acting in the opposite direction, reduces the main E.M.F.

The modern primary cells are mainly devices for the elimination of polarisation, by, so to speak, using up the hydrogen.

**55. The Leclanché Cell.**—The low-potential element of this cell (Fig. 33) consists of a rod of zinc placed in a solution of ammonium chloride (sal-ammoniac) contained in a glass vessel. A rod of carbon forms the high-potential element; this is placed in a porous pot, and is surrounded by broken carbon and black oxide (dioxide) of manganese. In many types the carbon is fitted with a cap of lead carrying the terminal; this, however, is conducive to the production of white lead, so that a better device is to fix the terminal to the carbon direct. The chemical reactions are as follows:—

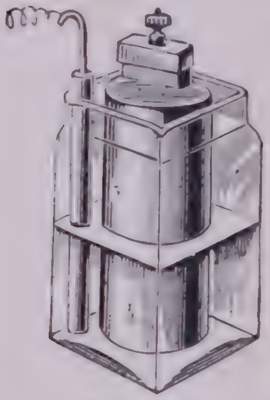


Fig. 33.

$$Zn + \underset{\text{Ammonium Chloride.}}{2NH_4Cl} = \underset{\text{Zinc Chloride.}}{ZnCl_2} + \underset{\text{Ammonia.}}{2NH_3} + H_2 \ldots\ldots\ldots (1)$$

$$H_2 + \underset{\text{Black Oxide of Manganese.}}{2MnO_2} = \underset{\text{Brown Oxide of Manganese.}}{Mn_2O_3} + H_2O \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

The hydrogen, however, is liberated more quickly than the manganese dioxide can use it up, so that after a short time polarisation sets in and the current falls off. If the cell is allowed to rest for a few minutes the manganese dioxide performs its work in accordance with equation (2), and the cell in consequence regains its strength; thus Leclanché cells are admirably adapted for intermittent work, such, for example, as bell-ringing and telephone calls.

The E.M.F. of a Lelanché cell is about 1·5 volts, and its resistance may amount to several ohms.

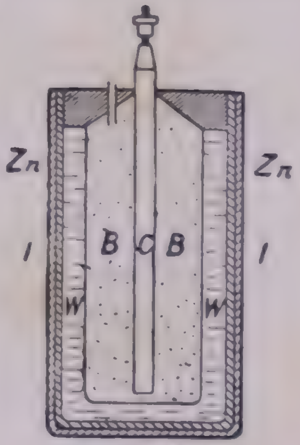


Fig. 33(*a*).

**56. Dry Cells.**—Nearly all the various forms of so-called dry cells are modifications of the Leclanché in principle.

The *E.C.C. type* (Fig. 33(*a*)) consists of a zinc cylinder, next to which is a paste *W* composed of plaster of Paris, flour, zinc chloride, sal-ammoniac, and water. Adjoining this is a second paste $B$ of carbon, manganese dioxide, zinc chloride, sal-ammoniac, and water. $C$ is a rod of carbon, forming the high-potential element of the cell. The whole is covered with a case of millboard, is sealed with pitch, and is provided with a vent for the escape of gas. The E.M.F. is about the same as that of an ordinary Leclanché, and the internal resistance is often less than ·5 ohm.

The *Hellesen Cell* consists of two cylinders of zinc, the inner one being perforated and lined with paper. Between these is a paste consisting of sal-ammoniac, plaster of Paris, and gum tragacanth. In the centre of the cell stands the carbon rod, around which is the depolariser, composed of manganese dioxide, plumbago, and sal-ammoniac. The whole is sealed with pitch, and provided with a gas vent. The internal resistance varies from ·2 to ·7 ohm, according to the size of the cell.

The main points in favour of dry cells are :—(1) they are compact and portable; (2) they may be placed in any convenient position; (3) they require very little attention; (4) they are more cleanly than the ordinary type of Leclanché.

*It should be noted in passing that the E.M.F. of a cell depends on the materials employed in its construction (and on the temperature), but it does not depend on the size of the plates or on their distance apart. The internal resistance does, of course, depend on the size of the plates and on their distance apart; the larger the plates and the nearer they are together the less the resistance.*

**57. Batteries—Current Calculation.**—The "groupings" (to form batteries) which the student must thoroughly understand are as follows :—

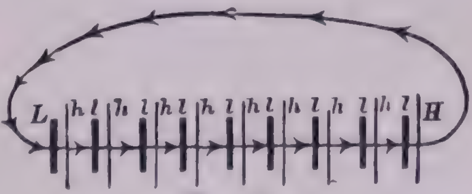


Fig. 34.

(1) Series Grouping (Fig. 34).—In this grouping the negative pole of one cell is joined to the positive pole of the next. If there are $n$ cells, each of E.M.F. $E$ and resistance $r$, the combined E.M.F. is $nE$ and the total internal resistance $nr$; hence, if $I$ be the current and $R$ the external resistance,

$$I = \frac{nE}{nr + R} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

*Extreme Cases.*—(*a*) If the external resistance be very large compared with the internal, the latter may be neglected and $I = nE/R$; this is $n$ times the current that one cell would give. (*b*) If the external resistance be very small compared with the internal, the former may be neglected, and $I = E/r$; this is the current which one cell alone would give. *Thus a series grouping lends itself to a large external resistance.*

(2) PARALLEL GROUPING (Fig. 35).—In this grouping all the high potential plates are connected, forming, as it were, one large plate, and similarly all the low potential plates are connected. Since the E.M.F. does not depend on the size of the plates, the combined E.M.F. is simply that of one cell, viz. $E$. The total internal resistance is, however, $1/n$ that of one cell, viz. $r/n$, (Art. 45) and the external current $I$ is given by

$$I = \frac{E}{\frac{r}{n} + R} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

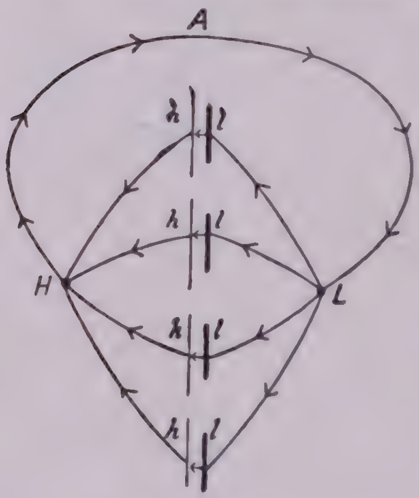


Fig. 35.

*Extreme Cases.*—(*a*) If the external resistance be very large, $I$ becomes $E/R$, the current which one cell alone would give. (*b*) If the external resistance be very small, $I$ becomes $nE/r$; this is $n$ times the current that one cell would give. *Thus a parallel grouping lends itself to a low external resistance.*

**58. Dry Cells in Wireless.**—In valve receiving sets in wireless, dry cells in series are almost invariably employed for what is called the **high tension (H.T.) battery**—a battery which is used to apply a high positive potential to the plates of the valves.

High tension batteries may have an E.M.F. of from 20 volts to 200 volts or more, according to circumstances, and as the E.M.F. of a single dry cell is of the order 1·4 volts, it will be seen that the number of cells in a high tension battery will vary from, say, 15 or 16 to quite large numbers.

High tension batteries are usually neatly arranged in strong cardboard boxes, the cells being well sealed in with paraffin wax or pitch. Tappings are taken from every third or fourth cell and connected to a hollow metallic socket, the upper open end of which projects above the wax or pitch. The positive and negative battery leads from the receiving set are attached to metallic pins, known as *wander plugs*, which fit into these sockets : in this way the voltage actually used can be varied. Graduated scales alongside the sockets indicate the voltage which is being tapped.

With continued use one or more cells in the high tension battery may become run down and useless, in which case wrong voltage is being applied to the valves and irritating crackling sounds will be heard in the telephones. When this occurs, the faulty cells must be found and short circuited by a wire, *i.e.* practically removed from the battery. The faulty cells are readily detected by means of a small voltmeter (reading say from 0—10 volts), by inserting leads from its terminals into various sockets in turn throughout the battery. It is best to use a voltmeter of what is called the " moving coil " type, and it should have a really large resistance—40,000 ohms or thereabouts. A cheap " moving iron " voltmeter, or a flash lamp bulb (which is sometimes recommended) should not be used in testing a high tension battery ; the latter, for example, may draw out, in testing, twenty times the current strength (of the order 12 milliamperes) which the battery is normally expected to give, and as a result the battery may be permanently damaged.

It should be remembered that polarisation sets in with dry cells if the current taken is excessive, or if they are kept continuously in use for a long time : in the latter case they recover, however, with rest.

It is sometimes necessary, in receiving sets employing several valves, to apply a slight positive or negative potential to the grid of a valve, as will be explained later : invariably this is done by means of one or two dry cells, the latter being then referred to as a **grid biasing battery**. Incidentally, for reasons which cannot be given at this stage, the use of grid bias cells tends to prolong the life of the high tension battery.

Yet another battery, known as a filament battery or low

**tension (L.T.) battery,** is necessary in valve receiving sets for the purpose of heating the filament of the valve. For this battery, accumulators (Art. 59) are nearly always used, but there is a type of valve known as a *dull emitter valve* which takes a filament current of about ·06 ampere only, at a small voltage, and with such a valve the low tension battery may consist of a few dry cells in series.

Further details of dry cells in connection with their chief application to wireless, *i.e.* as high tension batteries, will be given in later chapters.

**59. Principle of Accumulators or Secondary Cells.**—If acidulated water be decomposed by a current of electricity, the electrodes being platinum plates, and if, when the action has continued for some time, the battery be disconnected and the electrodes joined by a wire, it will be found that the voltameter gives for a short period a current in the direction anode to kathode through the connecting wire. This was employed by Ritter in the construction of the earliest secondary batteries.

In commercial secondary cells lead plates are employed. Consider two such plates, *A* and *K* (Fig. 36), immersed in dilute sulphuric acid (ten parts by weight of water to one of acid), and let a current of electricity be passed through the voltameter from *A* to *K*. The acidulated water will be decomposed into its constituent gases, hydrogen and oxygen, the latter appearing at the anode *A*, the former at the kathode *K*. The oxygen at the anode combines with the surface lead forming the dark brown peroxide of lead ($PbO_2$); the hydrogen at the kathode mostly rises to the surface, so that this plate remains in the metallic state.

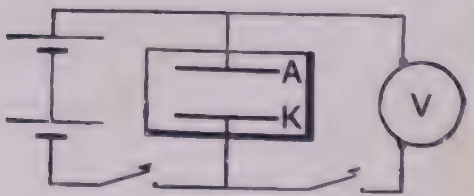


Fig. 36.

When the "charging" process, as it is termed, has continued for some time, let the battery be disconnected and the plates *A* and *K* joined through a voltmeter; the instrument will indicate about 2 volts at first, a current will flow through the outside circuit in the direction *A* to *K*, and, decreasing gradually, will after a time cease. On examining the plates it will be found that the peroxide has disappeared, and that both plates have lead sulphate ($PbSO_4$) formed on them, with traces of the monoxide ($PbO$).

The charging process may now be repeated by passing a current through the voltameter in the direction *A* to *K*. The nascent oxygen at *A* will convert the $PbSO_4$ (and any $PbO$) there into $PbO_2$, while the nascent hydrogen at *K* will reduce the products there to the metallic state; thus the electrodes are again in their "formed" condition, viz. lead peroxide ($PbO_2$) at *A*, lead ($Pb$) at *K*.

Such an arrangement is termed a **secondary cell, storage cell, or accumulator**; the *anode* is called the *positive plate*, and the *kathode* the *negative plate* of the cell. It should be particularly observed, however, that there is no accumulation or storing of electricity; fundamentally, what takes place is the transformation of electrical energy into the potential energy of separated ions, *i.e.* into "chemical potential energy"; and when the cell gives a current the energy transformation is merely reversed.

In the above it is mentioned that on the first "charge" the plate *K* remains more or less in its initial condition, and as such it does not readily combine with the sulphion $SO_4$ to form $PbSO_4$ at discharge. This defect is eliminated by adopting the "alternate" charge process introduced by *Planté*. The current is first passed through the electrolyte in the direction *A* to *K*, with the result that *A* is peroxidised; it is then reversed, in which step the oxygen at *K* forms $PbO_2$ there, while the hydrogen at *A* reduces the existing $PbO_2$ to porous spongy lead. This operation is several times repeated, with the final result that the last anode (positive plate) has a thick coating of dark brown lead peroxide, while the last kathode (negative plate) is coated mainly with metallic lead of a greyish colour in a porous spongy condition, readily acted on by the $SO_4$ during discharge. The process is known as "forming" the plates.

To obviate the tedious "formation" of the Plante plates, *Faure* coated the plates, prior to charging, with a paste of red lead ($Pb_3O_4$) and sulphuric acid, the adherence of the paste to the plates being assisted by a covering of paper; on charging,

R B A I . I S H . M LIBRA
Acc. No. 1702
U.D.C No: 538.56
Date; 5-1-81

the red lead on the kathode becomes quickly reduced to spongy metal, while that on the anode becomes peroxidised. Later the *Sellon-Volckmar* plates were introduced, which, being constructed in the form of grids, more effectively secured the paste. Thus accumulators follow in general two specific types—(1) the Planté or naturally " formed " cell, and (2) the Faure or pasted grid cell ; frequently they are of a composite character, having Planté positives and pasted negatives, since pasted positives, particularly in central station batteries, are liable to disintegration (falling of paste).

The poles of an accumulator are generally distinguished by painting the terminal of the anode or positive plate red, and that of the kathode or negative plate black.

As already indicated, in the valve receiving sets used in wireless, accumulators are nearly always used for the purpose of heating the filament of the valve, and are known as *filament batteries* or *low tension* (*L.T.*) *batteries.* Such may consist of one accumulator (2 volts), two accumulators in series (4 volts), or three accumulators in series (6 volts), according to the valves employed.

Accumulators are also employed as high tension batteries in some cases : it is more usual, however, to use dry cells.

**60. Facts about Accumulators, and Hints on their Care and Management.**—The E.M.F. of an accumulator, whether large or small, is about 2 volts, but the current which can be taken from it depends, amongst other things, upon the size of the plates and their distance apart. To obtain large currents with plates of reasonable dimensions the arrangement shown in Fig. 37 is adopted. This depicts a large thirteen plate cell, the positive consisting of six positive plates connected together, and the negative consisting of seven negative plates similarly connected together : thus each positive has a negative on both sides of it.

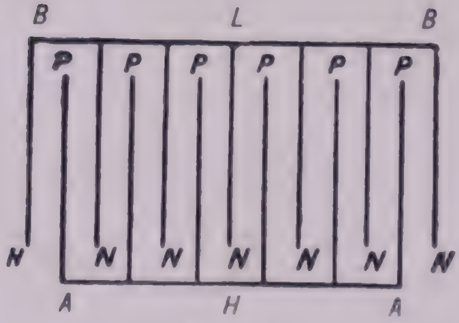


Fig. 37.

To keep the internal resistance as low as possible the individual plates are placed very near each other. To prevent internal contact between these plates, glass tube separators or ebonite forks are placed between them. The Chloride Co. use sheet separators of specially prepared thin wood (Fig. 38), and the Hart Co. use sheets of nitrated cellulose fibre.

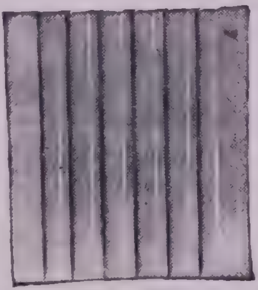


Fig. 38.

There must be a good space between the plates and the bottom of the containing vessel to hold any active material which may fall from the plates, so that such active material may not join two opposite plates, thus short circuiting the cell and spoiling it. With the larger cells contained in glass boxes, the usual practice is to provide the plates with projecting shoulders which enable them to be suspended at the correct height from the edges of the containing vessel. Supporting blocks of wood or vulcanite placed in the bottom of the cells are other usual methods. Incidentally, the containing vessels for wireless accumulators are usually of best quality celluloid: also celluloid lids (Fig. 45) are generally sealed to the tops of the cases, thereby preventing impurities from entering the cells, and eliminating the possibility of the metal terminals becoming corroded owing to the flooding and creeping of the acid.

The **capacity** of an accumulator is measured in *ampere-hours* : thus if a large accumulator has a capacity of 704 ampere hours and the greatest discharge current as stated by the makers is 64 amperes, it will be able to give this current for 11 hours.

For most purposes accumulators are designed to give a certain current on a 9 or 10 hour discharge rate, *i.e.* the best results are obtained if the current taken from the cell be such that it is completely discharged in 9 or 10 hours. Thus if an accumulator is stated to have a capacity of "30 ampere-hours actual," then assuming the 10 hour basis, since $\frac{30}{10} = 3$, good results will be obtained by taking a current of 3 amperes from the cell. Further, this accumulator would deliver a current of $1\frac{1}{2}$ amperes for more than 20 hours, for *the capacity of an accumulator increases if the discharge current is reduced*, *i.e.* its capacity is more than 30 ampere-hours when discharged at a less current value than 3 amperes. On the other hand, the accumulator would not deliver 6 amperes for 5 hours, for *the capacity decreases as the discharge current increases.*

Some makers label the capacities of accumulators as "ignition capacity." From a wireless point of view this term is very misleading, and the number given in such cases should be at least halved to obtain the proper capacity.

The maximum discharge rate as specified by the makers' should never be exceeded, otherwise the intense chemical action and heat produced will result in unequal expansion of the plates, excessive formation of a hard lead sulphate, loosening of the paste, and bending or buckling of the plates—the last named producing internal short circuits, and eventually spoiling the cells. For like reasons, accumulators should never be short circuited outside, for their internal resistance is so low (of the order ·001 ohm, depending on the number and size of plates and their distance apart) that heavy discharge currents will flow, and sulphating, disintegration, and buckling will follow. Sulphating is indicated by a hard white surface forming on the plates : this hard sulphate must not be confused with the ordinary sulphate produced on discharging.

When an accumulator is discharged two factors are affected, viz. the specific gravity of the acid and the voltage of the cell : both of these decrease, and both may be used to indicate the condition of the cell.

The values of the specific gravity vary with the type of accumulator, but in a general way it may be stated that (1) when fully charged the specific gravity is about 1·25, (2) when half discharged it is about 1·18, and (3) when fully discharged it is about 1·11. It is, however, best to be on the safe side, and to consider a drop in specific gravity to 1·15 to be an indication that the cell should be recharged : if run below this value there is always the possibility of the plates sulphating. Instruments known as *hydrometers* are used for testing the specific gravity.

When fully charged, the E.M.F. of a cell is just over 2 volts —frequently 2·2 volts. When the cell is supplying a current, the E.M.F. drops fairly quickly to 2 volts, remains at about 2 volts over a long period, and then gradually falls. When it reaches 1·8 volts (current flowing) the cell should be regarded as discharged : it should never run below this value, otherwise sulphating and buckling of the plates may follow. It may be noted in passing that in a general way the positive plates of a fully charged cell are of a deep chocolate colour, whilst the negatives are of a slate-grey colour : these colours are a guide to the condition of the cell.

Accumulators should be kept well charged ; they should on no account be permitted to stand for any length of time in an uncharged condition, or the amount of hard sulphate will become excessive. When not in use short chargings should be given occasionally, say fortnightly, till the plates gas freely.

Any evaporation of the electrolyte must be compensated for by the addition of pure water : the acid must always be kept above the level of the tops of the plates. Incidentally, when diluting strong acid for use with accumulators, the acid should be poured into the water, not the water into the acid.

Instructions as to the first charge to be given to an accumulator, and also details as to recharging, are invariably given by the makers, and these instructions should be strictly followed. As a general rule, in the case of a new battery, the acid should not be put into the cells until all arrangements for charging are complete, otherwise the formation of hard sulphate will impair the efficiency of the cells. The acid must be of the purest, of specific gravity about 1·2, and must reach to a height of not less than ½ in. above the plates. The proper value of the charging current as stated by the makers should then be passed for the number of hours also stated, and the battery must not be used until the acid in each cell has turned milky and gas is freely evolved from both plates, nor until the specific gravity of the acid has ceased to rise. In recharging, if the rate of charge is not known, it can be roughly obtained by dividing the capacity in ampere-hours by 12 : thus a 60 ampere-hour battery may be recharged at 5 amperes, and in a general way, about 67 ampere-hours will be needed in the recharge (see below), so that this current of 5 amperes will be required to flow for from 13 to 14 hours.

The **quantity efficiency** of an accumulator is given by :—

$$\text{Quantity Efficiency} = \frac{\text{Ampere-hours given out at discharge}}{\text{Ampere-hours put in at charge}},$$

and is of the order 85 to 90 per cent. (it may reach 95 per cent. if discharge immediately follows charge) : hence the statement above that the 60 ampere-hour cell will require about 67 ampere-hours in the recharge.

The **energy efficiency** of an accumulator is given by the expression :—

$$\text{Energy Efficiency} = \frac{\text{Watt-hours given out at discharge}}{\text{Watt-hours put in at charge}},$$

and is of the order 65 to 75 per cent.

Care should be exercised in carrying wireless accumulators in celluloid cases to and fro for charging purposes. Rough handling may buckle the plates or burst the seams of the case. Wooden or other crates should always be used for carrying accumulators.

If we assume roughly that a single valve receiving set (bright emitter valve) is run, say, four hours per night for a week, and that the valve takes half an ampere, the total ampere-hours required for the week will be $\frac{1}{2} \times 7 \times 4 = 14$ : hence a 20 ampere-hour (actual) capacity accumulator battery will meet the requirements very well indeed. For a two valve set under similar conditions, the ampere-hours required will be $1 \times 7 \times 4 = 28$ : hence a 30 ampere-hour (actual) battery will be suitable. Similarly for a three valve set a 40 ampere-hour capacity may meet the case. It is always wise, however, to use a battery of as large a capacity as possible : small capacity batteries are not economical.

**61. Types of Accumulators.**—The student should examine a few different makes of accumulators, and consult the details given in the manufacturers' catalogues. Only one or two types, including large ones suitable for heavy electrical engineering, are described here in order to indicate the construction and appearance of accumulators in general.

**62. The E.P.S. Accumulators.**—The E.P.S. accumulators are either composite or of the Faure type : the following particulars apply to the latter :—The negative plates are grids of lead, of which two types are shown in Figs. 39 and 40 : in Fig. 39 the apertures ($\frac{3}{16}$ inch square) carry four or eight projecting claws which grip the active material. The paste for the negatives is made of pure well-ground litharge and sulphuric acid of specific gravity 1·2 (cold). The positives are grooved horizontally (Fig. 41), and the grooves are filled with a paste of red lead and sulphuric acid of specific gravity 1·1 (cold).

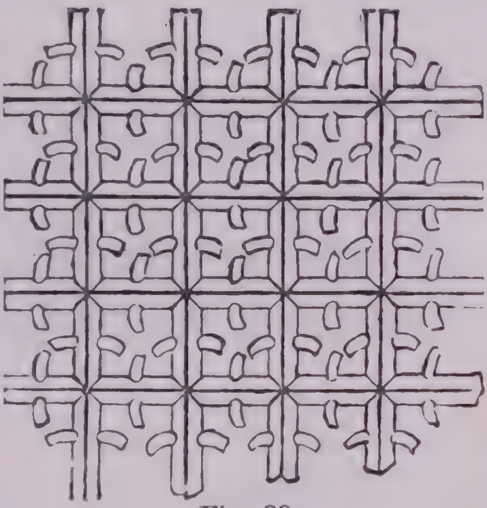


Fig. 39.

**63. The Chloride Accumulators.**—The positive plates of these cells are constructed as follows:—A plate with circular holes is cast, the material being an alloy of lead with antimony, the latter giving the plate greater strength. Pure lead in the form of a tape, about $\frac{7}{16}$ inch in width, is passed through gimpers, which rib it and sever it into definite lengths. These are rolled into coils and pressed into the circular apertures in the plate, the whole being next subjected to a pressure of over 70 tons in a hydraulic press. Plates thus constructed are fixed as anodes in a voltameter with temporary kathodes, and a current is passed for several

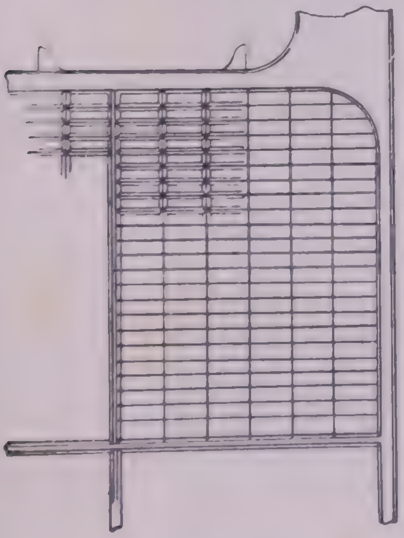
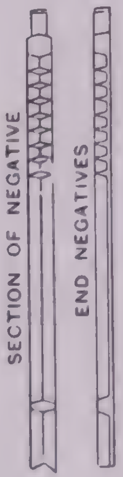


Fig. 40.



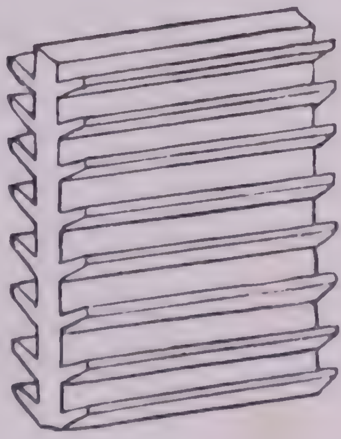


Fig. 41.

days, with the result that the liberated oxygen produces on them a large amount of lead peroxide.

The general appearance of a portion of the positive plate is depicted in Fig. 42.

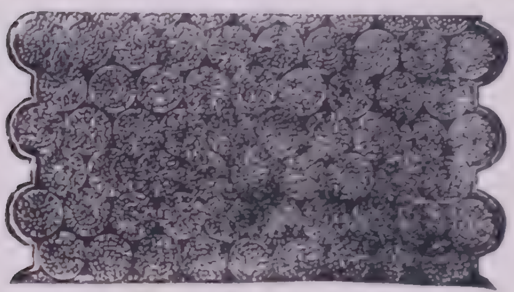


Fig. 42.

The negative plate consists of an antimonial perforated lead cage in two halves, the intervening space forming pockets which act as receptacles for the active material. In the construction of this plate, perforated sheet lead is cut to shape and laid in a mould and an antimonial lead frame is cast on to it. This forms a

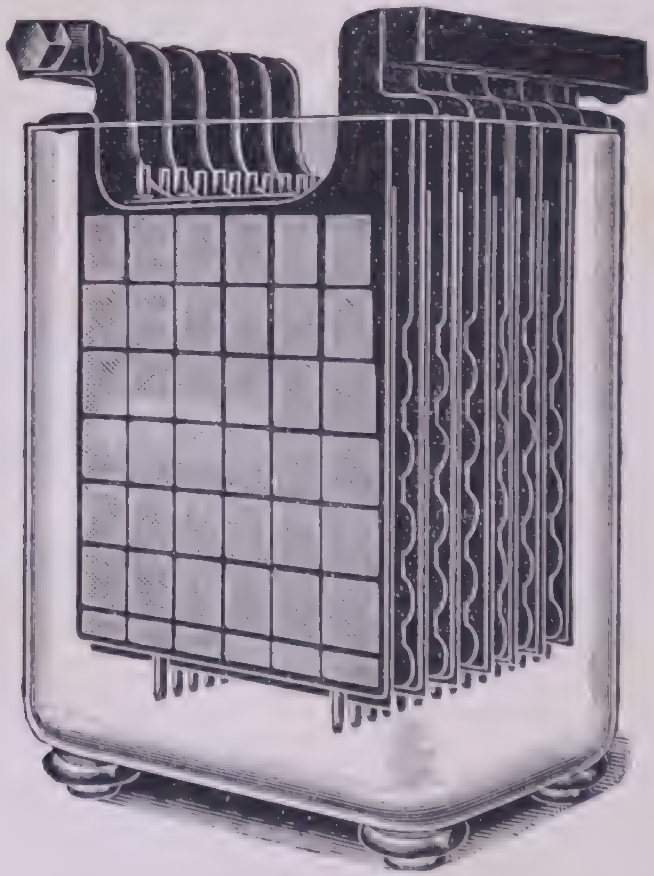


Fig. 43.

half plate on which a corresponding half is placed after the active material has been inserted, and the two halves are then riveted together by passing under a press specially designed for the purpose. The paste is made by a combination of raw materials which, after reduction, produces spongy lead in a highly porous form.

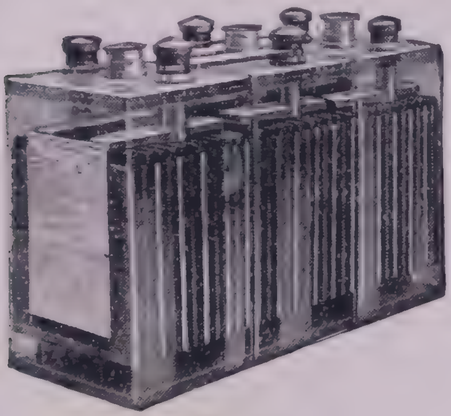


Fig. 44.

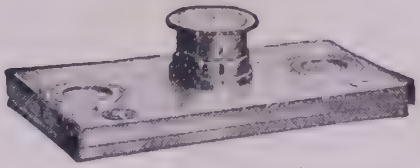


Fig. 45.

The above is known as the "Box" negative and is well adapted for central station work. The plates are provided with projecting lugs by which they hang on the edge of the containing glass vessel, and the positives and negatives are separated by thin sheets of wood. The cell is shown complete in Fig. 43.

The Exide battery of the Chloride Co. is a favourite one for wireless work, and its general construction will be gathered from Figs. 44, 45. Fig. 44 depicts a 6 volt battery consisting of three accumulators in celluloid boxes, the three boxes being cemented together. Fig. 38 shows one of the thin wooden separators which is used between adjacent positive and negative plates to prevent internal contact and short circuiting. Fig. 45 shows the celluloid lid which is sealed to the top of each accumulator: it is provided with a central opening (fitted with a cap) for the insertion and testing of the acid.

No. 103
Date
BANGALORE

# CHAPTER V.

## CAPACITY AND INDUCTANCE

**64. Introduction.**—It might almost be said that the two essentials of a wireless installation are capacity and inductance, for it is upon these that a factor about which the student will have heard so much—*the wave length of the wireless wave*—depends. Capacity and inductance will therefore be dealt with somewhat fully in the present chapter, although in a strictly elementary manner, suitable for the student at this stage of his progress.

**65. Principle of Condensers.**—To simplify matters for the beginner, we will treat this from the point of view of both the older and the newer theories of electrification.

Consider an insulated metal plate *A* (Fig. 46) joined by a wire to the positive pole of a battery or electrical machine. Electricity flows to *A* until the plate acquires the limiting potential *V* of the generator (battery or electrical machine). When this condition is reached no further charge can be accumulated on *A*, for electricity will not flow between two bodies whose potentials are the same. It is, moreover, evident that the larger the plate the greater the capacity, and therefore the greater the charge necessary to bring it up to the potential of the generator.

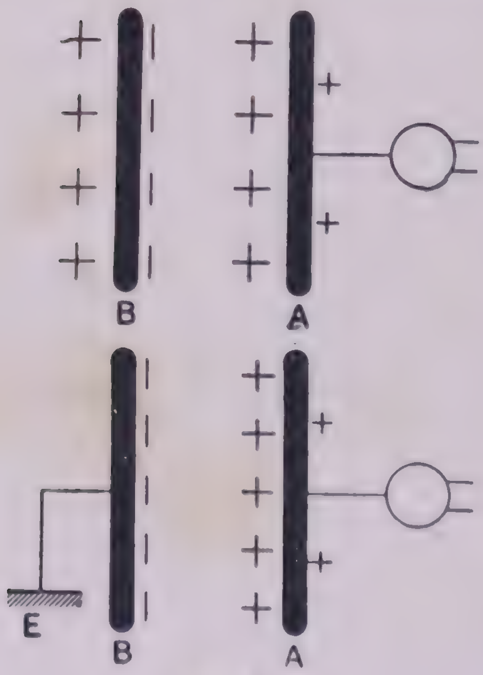


Fig. 46.

Take, now, a second insulated metal plate *B*, and with *A* still at potential *V* let *B* be placed parallel to, and, say, four inches from it. Inductive displacement occurs (Art. 10), electricity being urged to the side of *B* remote from *A* ; thus the near side exhibits a negative charge, the far side a positive charge, and the uniform potential of *B* is $+ v$ say, this being somewhat less than *V* in magnitude.

Now consider the effect of *B* on the potential of the plate *A*. The actual potential of the latter is the resultant of :—(1) the free positive potential *V* due to its own charge, (2) the induced negative potential due to the negative charge on *B*, and (3) the induced positive potential due to the positive charge on *B*. The two latter opposing influences nearly counteract each other ; but the negative charge, being somewhat nearer than the positive, has the advantage, and therefore on the whole *the potential of the plate A is weakened a little.* Clearly, then, an additional charge can now be given to it from the generator until its potential is once more equal to *V* as at first. Clearly also the nearer *B* is to *A* the more marked will be the lowering of the latter's potential.

If *B* be earthed, electricity will flow out of it until its potential is reduced to zero. *B* has now a negative charge only, and, as a matter of fact, *a greater negative charge than in the case considered above*, for, when earthed, more electricity flows out of it to reduce its potential to zero (thus leaving a greater negative charge) than previously existed as a positive charge on the far side of the plate. The increased negative charge reacting on *A* lowers the latter's potential, and as there is no positive to counteract its influence it is evident that *the potential of A will be considerably weakened*, and, in consequence, a much greater charge must be given from the generator to raise the potential to its original value *V*—in short, *the capacity of A is considerably increased.* To summarise :—

*The potential of an insulated charged conductor is weakened and its capacity is increased when an insulated uncharged conductor is brought near, and the effects are enormously increased if the latter be earthed.*

Such an arrangement of conductors separated by an insulator is called a **condenser** : the conductors are termed the **coatings**, and the insulator the **dielectric** of the condenser.

It has been indicated that glass, wax, mica, etc., allow inductive influence to take place through them better than air and are said to have a higher dielectric constant or specific inductive capacity ; with one of these substances as dielectric the effects mentioned would be still more marked. For this reason, and also owing to their greater mechanical rigidity, solid dielectrics of glass, wax, and mica are frequently employed in practical condensers.

In practice condensers are usually charged by means of batteries, *A* being joined to the positive pole of the battery and *B* to the negative pole. This simply means that whilst *A* takes the positive potential of the positive pole of the battery, *B*, instead of being at zero potential, takes the negative potential of the negative pole of the battery. The action and explanation are somewhat similar to the preceding.

We will now look at the action of a condenser from the point of view of the electron theory. Imagine a condenser joined to a battery, *A* to the positive and *B* to the negative pole. As soon as the connections are made there is a momentary rush of electrons (negative) from the negative pole of the battery to *B*, and electrons rush out of *A* to the positive pole : this really takes place in the manner explained in Art. 17. Thus on *B*, the negative plate of the condenser, we have an excess of electrons, whilst on *A*, the positive plate of the condenser, we have atoms which have each lost an electron—*positive ions* as they are called (Art. 6).

The positive ions of *A* and the negative electrons on *B* attract each other with an intense force. The army of electrons on *B* is anxious to get across the dielectric to make up the deficit of electrons in the positive ions of *A*, and the positive ions of *A* are just as eager to have them. Now the electrons on *B* cannot themselves get across the dielectric to *A* but they do, as it were, the next best thing—they *try* to drive electrons out of the atoms of the dielectric (themselves taking their place), leaving these evicted electrons to drive out other electrons and take their place, and so on until finally electrons would reach *A*. At the same time the positive ions of *A* are assisting in the work by trying to pull out the electrons and to repel the resulting positive ions in the dielectric.

The dielectric, however, is a substance which clings to its electrons: it contains practically no detachable electrons. All that happens therefore is that the orbits of the electrons round the positive nucleii (or protons) in the atoms of the dielectric are *strained* as shown in Fig. 47: the positive nucleus of any dielectric atom is pushed by *A* and pulled by *B* down towards the electrons on *B*, and the electrons in any dielectric atom are pulled by *A* and pushed by *B* up towards the positive ions of *A*. The final state of affairs is that the plate *A* has a large positive charge and *B* a large negative charge, *the medium is strained*, and we have what is spoken of as a *charged condenser*, but no "flow of current" across the dielectric. The strain lines are shown in the right hand side of the figure.

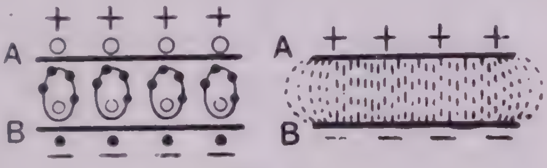


Fig. 47.

66. **Capacity of a Condenser.**—*The capacity of a condenser is measured by the quantity of electricity which must be given to it to establish unit potential difference between the coatings*; if one coating be earthed the capacity of the condenser will be measured by the quantity of electricity necessary to raise the other coating to unit potential, *i.e.* the capacity of the condenser is numerically the same as the capacity of the plate *A* when *B* is earthed.

The practical unit of *capacity* is the **farad**; **a condenser has a capacity of one farad if a charge of one coulomb produces a P.D. of one volt between its coatings.**

Capacities of condensers used in wireless are generally expressed in **microfarads**: a microfarad is $\frac{1}{1000000}$ of a farad. The symbol $\mu F$ is generally used for this latter unit in practice; thus ·0005 $\mu F$ means ·0005 microfarad. A *micro-microfarad* ($\mu\mu F$) is one millionth of one millionth of a farad.

In electrical theory it is shown that capacity can be expressed in terms of a length (strictly a length multiplied by a certain constant for the aether), and for calculation purposes in wireless it is sometimes convenient to express the capacities of aerials and coils in terms of lengths. Without going into details it may be mentioned that a capacity of a microfarad expressed in this way is about 9,000 metres, and a micro-microfarad is $\frac{9}{10}$ of a centimetre; hence for approximate work a capacity of a micro-microfarad may be expressed as one centimetre. At this stage we merely mention this in case the student comes across it in his general reading.

**67. Specific Inductive Capacity or Dielectric Constant.**—Reference has been made to the fact that some dielectrics allow inductive influence to take place through them better than air and are said to have a higher **specific inductive capacity** or **dielectric constant**: this must now be defined in a little more detail.

Imagine two *precisely equal* condensers, one with air and the other with a medium $x$ for dielectric, and imagine their capacities to be compared. **The ratio of the capacity of the condenser with dielectric $x$ to the capacity of the equal air condenser measures the specific inductive capacity of $x$**, *i.e.*

$$\frac{\text{Capacity of condenser with dielectric } x}{\text{Capacity of equal air condenser}} = \begin{Bmatrix}\text{Specific Inductive} \\ \text{Capacity of } x\end{Bmatrix} = K,$$

$$\therefore \begin{Bmatrix}\textbf{Capacity of condenser} \\ \textbf{with dielectric } x\end{Bmatrix} = K \begin{Bmatrix}\textbf{Capacity of an equal} \\ \textbf{air condenser}\end{Bmatrix}.$$

Thus if the capacity of an air condenser such as is shown in Fig. 46 be ·0002 microfarad, and if the space between the plates be then completely filled by mica, the capacity of the mica condenser so formed will be about (6·6 × ·0002) microfarad, since 6·6 is approximately the dielectric constant of mica.

From what has been said it follows that the capacity of a condenser depends on :—(1) the size of the plates—the larger the plates the greater the capacity, (2) the distance between the plates—the less the distance the greater the capacity, (3) the dielectric constant or specific inductive capacity of the dielectric—the greater the value of the dielectric constant the greater the capacity.

**68. Joining Capacities in Parallel.**—This method of grouping condensers is shown in Fig. 48; in it all the *A* plates are joined together and connected say to the positive pole of the charging battery, whilst all the $B$ plates are joined together and connected to the negative pole of the battery. It is clear that the capacity of the compound condenser is the sum of the capacities of the individual condensers: that is if $C_1$, $C_2$, $C_3$ be the capacities of the three individual condensers of Fig. 48, and $C$ the total capacity :—

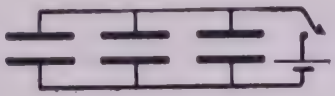


Fig. 48.

$$C = C_1 + C_2 + C_3.$$

If the condensers were alike, say each of capacity $C_1$, then in Fig. 48 the joint capacity would be $3C_1$, *i.e.* three times the capacity of one of them. Thus **joining condensers in parallel increases the capacity.**

The wireless student must note this point carefully. If two condensers of capacities 3 and 6 microfarads be put *in parallel*, the total capacity becomes $3 + 6 = 9$ microfarads. If two wires of resistances 3 and 6 ohms be put *in parallel*, the total resistance becomes $\frac{3 \times 6}{3 + 6} = 2$ ohms. The difference in the two cases should be particularly noticed.

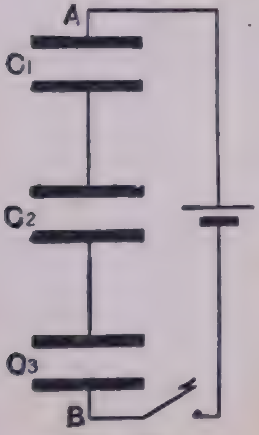


Fig. 49.

**69. Joining Capacities in Series.**—This arrangement is shown in Fig. 49. Since the outflow from one condenser is the charge on the next, the charge $Q$ on the positive coating of each must be the same and equal to that given to the first condenser. If $V$ be the potential difference between $A$ and $B$, $V_1$, $V_2$, $V_3$ the potential differences between the coatings of the separate condensers, $C_1$, $C_2$, $C_3$ the individual capacities, and $C$ the joint capacity :—

$$V = V_1 + V_2 + V_3,$$

$$i.e.\ \frac{Q}{C} = \frac{Q}{C_1} + \frac{Q}{C_2} + \frac{Q}{C_3},$$

$$\therefore\ \frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}.$$

If the condensers were alike, say each of capacity $C_1$, then in Fig. 49 we would have $\frac{1}{C} = \frac{3}{C_1}$ or $C = \frac{1}{3} C_1$, *i.e.* the joint capacity would be only one-third of the capacity of one of them. Thus **joining condensers in series reduces the capacity.**

The wireless student should again note this point carefully. If two condensers of capacities 3 and 6 microfarads be put *in series* the total capacity becomes $\frac{3 \times 6}{3 + 6} = 2$ microfarads $\left( \frac{1}{C} = \frac{1}{3} + \frac{1}{6} = \frac{3 + 6}{3 \times 6} \quad \therefore C = \frac{3 \times 6}{3 + 6} = 2 \right)$. If two wires of resistances 3 and 6 ohms be put *in series* the total resistance becomes $3 + 6 = 9$ ohms. The difference in the two cases should be particularly noticed.

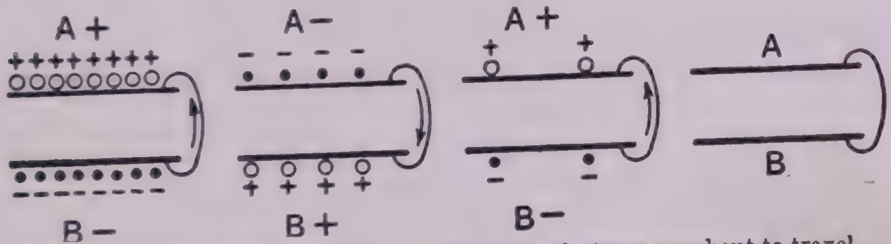
**70. Discharging a Condenser.**—If the two plates of a charged condenser be connected by a wire a discharge takes place through the wire, and the potentials of the plates are equalised.

Adopting the older theory, it is said that the plate $A$ has a surplus of electricity and is positively charged: $B$ has an equal deficit of electricity and is negatively charged. Further the plate $A$ is at a higher potential than the plate $B$. On joining $A$ and $B$ by a wire, electricity flows from the high potential plate $A$ to the low potential plate $B$, the surplus of $A$ thus making up the deficit of $B$ and the potentials of the plates becoming equalised.

According to the electron theory, piled up on the positive plate $A$ we have a number of positive ions, *i.e.* atoms each of which is deficient of one electron, whilst piled up on the negative plate $B$ we have an equal number of electrons. On joining $A$ and $B$ by a wire the electrons "travel" (in the manner indicated in Art. 17) along the wire from $B$ to $A$, thus making up the deficit of electrons in the positive ions on $A$, and easing $B$ of its surplus electrons: the potentials of the plates are equalised.

Actually the discharge of a condenser is rarely such a simple matter as is outlined above. To fix ideas let us imagine that we start off with a charged condenser, having, say, 8 surplus positive ions on $A$ and 8 surplus negative electrons on $B$ ($A$ *is positively charged* and $B$ *negatively charged*), and let

*A* and *B* be now joined by a wire (Fig. 50). Electrons rush round from *B* to *A*, but if the resistance of the wire is not too large, so great is the rush that *more than* 8 electrons leave *B*. Suppose 12 electrons rush round from *B* to *A*. Clearly 8 of these will satisfy and neutralise the 8 positive ions on *A*, leaving *A* with a surplus of 4 electrons, *i.e. A is now negatively charged*; similarly *B* has four positive ions, the remains of the four atoms from which the four extra electrons cleared out, *i.e. B is now positively charged.*



The arrows indicate the direction in which the electrons are about to travel.

Fig. 50.

Electrons now rush from *A* to *B*, but again so great is the rush that more than 4 electrons leave *A*. Suppose 6 electrons rush round from *A* to *B*. From the preceding it follows that *A* is left with 2 surplus positive ions, the remains of the two atoms from which the two extra electrons have been obtained, *i.e. A is again positively charged.* Similarly *B* has got two more electrons than it requires, *i.e. B is again negatively charged.*

The above actions are repeated, the rushes backwards and forwards getting less and less each time until they cease altogether, matters becoming quite normal with *A* and *B* at equal potentials. Fig. 50 depicts the results. Of course in practice it is not a matter of eight electrons and eight ions but of millions.

Such a discharge as is indicated above is called an **oscillatory discharge**, and discharges of this type are much in evidence in wireless. A rush from *B* to *A* is termed an **oscillation**, a double rush from *B* to *A* and back from *A* to *B* is termed a **vibration**, and the number of vibrations in one second is called the **frequency**.

Incidentally it is well known that if a steel spiral spring be fixed by one end so as to hang vertically and be then pulled and let go, it will oscillate up and down, and the greater the "stiffness" the more rapid the movement, *i.e.* the greater the frequency. In the oscillating condenser circuit, increasing the capacity really corresponds to decreasing the stiffness, *i.e. an increase in the capacity decreases the frequency and a decrease in the capacity increases the frequency.* This is also clear from the fact that a small capacity condenser will charge and discharge quicker than a big one.

**71. Condensers in Practice.**—A convenient type of standard condenser for testing purposes is constructed of alternate sheets of tinfoil (thin lines in Fig. 51) and paraffined paper or mica (thick lines), the odd conducting sheets being bunched together and connected to one terminal *A*, the even numbers being joined to terminal *B*; the arrangement is thus equivalent to two large plates separated by a thin and good dielectric. Such condensers are frequently of $\frac{1}{3}$ microfarad capacity, this being approximately the capacity of one knot of the Transatlantic cable.

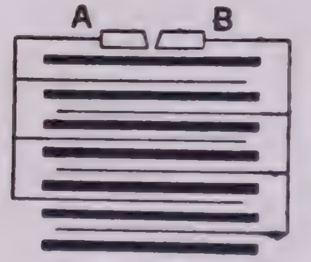


Fig. 51.

The small **fixed condensers** used in wireless work are constructed in the manner indicated above, but the capacities used in wireless receivers are very much smaller than those of standard condensers.

A **variable condenser**, as the name suggests, is one the capacity of which can be readily altered, and these are extensively used in wireless. The most common type employs an air dielectric, the variable capacity being obtained by rotating one set of metal plates into and out of another fixed set of metal plates, the rotating plates being all metallically connected together and forming one coating of the condenser, the fixed plates being similarly connected and forming the other coating of the condenser. Both fixed and moving plates are semicircular in shape to obtain a uniform increase or decrease *of capacity* as the moving plates are rotated into or out of the fixed plates. It should be noted that the capacity is greatest when the moving plates are completely inside the fixed plates, and least when the moving plates are completely outside the fixed plates. The principle of such a condenser will be gathered from the plan of the plates given in Fig. 52.

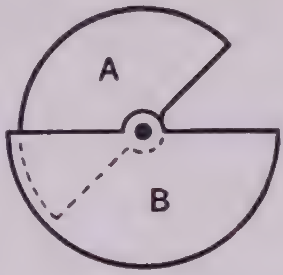


Fig. 52.

Another type of variable condenser is known as the **square law condenser**, and in the best wireless receivers it has replaced the ordinary form referred to above. To explain the principle of this condenser, however, we must anticipate certain facts which are dealt with in Chapter VII. : the student will probably have no difficulty in understanding them even at this stage.

In wireless reception condensers are largely used to **tune**, as it is termed, the receiving set to a particular *wave length* (a name which will be explained later), *i.e.* to make the receiver respond to the wireless waves from a particular transmitting station. Now in the case of the oscillatory discharge of a condenser dealt with in Art. 70, it has been stated that the larger the capacity the lower is the frequency of the vibrations. Similarly, in tuning a receiving set to wireless waves, an increase in the capacity of the tuning apparatus tunes the set to a lower wave frequency and, as will be seen later, this really means to a greater wave length ; further, decreasing the capacity tunes to a shorter wave length.

Wave length, however, is not directly proportional to capacity, but *it is proportional to the square root of the capacity* ; thus if the capacity is increased four times the wave length to which the apparatus is tuned is not four times but twice what it was before, and if the capacity is increased sixteen times the wave length to which it is tuned is only four times what it was before.

Clearly then, if we make a condenser with plates so shaped that *the capacity is proportional to the square of the number of degrees the moving plates turn*, the wave length will be proportional to the angle of rotation of the moving plates : in other words, if we were listening in to a station sending out a wave length of 250 metres and the tuning condenser was at 10°, and if we wished to get another station transmitting a

500 metre wave, it would only be necessary to rotate the condenser to about 20°. (We are assuming a usual tuning circuit and that the inductance is fixed). A condenser made in the manner indicated is called a *square law condenser*. Such a condenser really gives a straight line if we plot the relation between rotation and wave length, whilst the ordinary condenser gives a straight line if we plot the relation between rotation and capacity, and in wireless the former is much to be preferred.

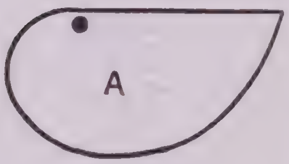


Fig. 53.

Fig. 52 as we have seen gives the semi-circular shape of the ordinary variable condenser plates. Fig. 53 gives roughly the "cam" shape of the moving plates of the square law condenser.

Fig. 54 shows types of modern condensers. One coating is fixed, and consists of a number of semicircular brass plates arranged parallel to each other, connected together and to one terminal of the condenser. The other coating is movable. It consists of a number of cam shaped brass plates attached to a vertical spindle and capable of rotation into or out of the fixed coating. As stated, the more the movable coating is rotated into the

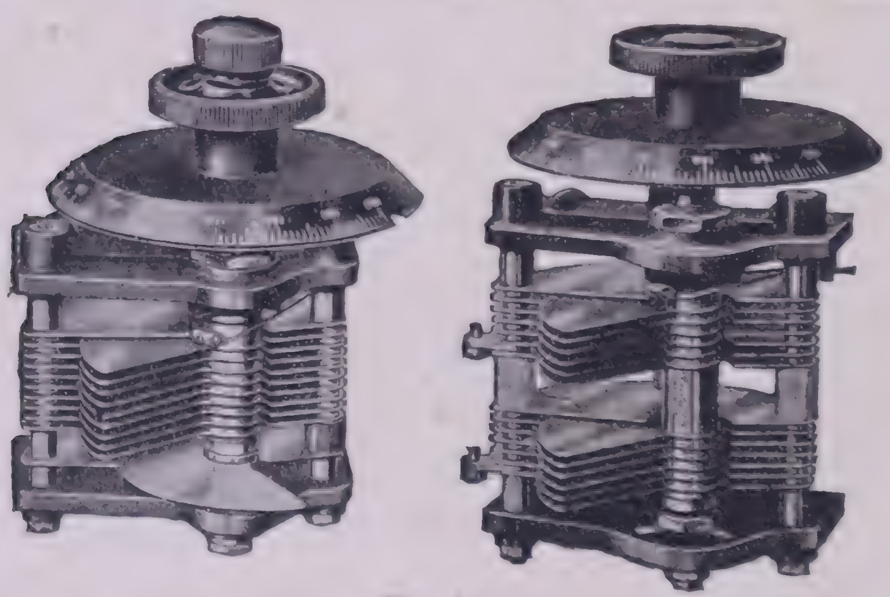


Fig. 54.

fixed coating the greater is the capacity. In the figure on the right the fixed plates are in two sets, insulated from each other, and either one set or both can be used.

For very fine tuning in wireless a small variable condenser known as a **vernier condenser** is employed. It is joined across the main variable condenser, *i.e.* the moving plates of both condensers are connected together and the fixed plates of both are connected together. Sometimes the two condensers are combined in the one instrument (Fig. 54—left).

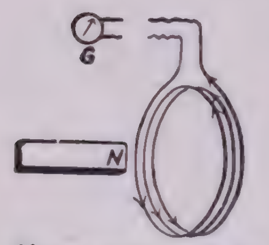
The aerials used in wireless are condensers, the wire forming the one coating, the earth and earth-joined bodies the other coating, the intervening air being the dielectric. For most practical purposes the capacity may be taken to be between 1·5 and 2·1 micro-microfarads ($\mu\mu F$) per foot.

Condensers used in wireless transmitting circuits have to stand high voltages and large currents. Condensers with ebonite or glass as dielectric are often used: they are frequently immersed in oil to prevent sparking or " brushing " along the edges.

It may be mentioned in passing that in a wireless receiver condensers are used for other purposes than tuning the set to the waves from a particular transmitting station. They are employed in places as " blocking " condensers to stop the flow of a direct current (for such a current cannot get through a condenser), and they are also used as " by pass " condensers for oscillatory currents (for such currents can " work through " a condenser, as will be seen later). Readers with valve sets should note that the grid condenser, amongst other duties, acts in the former capacity, since it prevents direct current from the high tension battery from getting to the grid. The condenser sometimes employed across the telephones or across the high tension battery is an example of the " by pass." The various uses are, however, dealt with in subsequent chapters.

**72. Induced E.M.F.'s and Currents.**—In 1831 Faraday showed that if a magnetic field in the vicinity of an electric circuit be changed in any way an E.M.F. is developed in the circuit, such E.M.F. lasting only while the change is taking place: E.M.F.'s and currents produced in this way are spoken of as **induced** E.M.F.'s and currents respectively. The more rapid the change the bigger are the induced E.M.F. and current.

**73. Induction of Currents by Magnets.**—If a magnet be moved in the neighbourhood of a coil in such a way that the number of magnetic lines passing through the coil is altered, then a current is produced or *induced* in the coil so long as the alteration lasts. If the magnet be fixed and the coil be moved the same thing occurs. A simple experiment will illustrate this :—



*Magnet approaching Coil*

Fig. 55.

Fig. 55 shows a coil connected to a galvanometer (G). On quickly inserting the N pole of a magnet the galvanometer is momentarily deflected, showing that a current is induced in the coil, and from the direction of the deflection it can be deduced that the current is *counter-clockwise* looked at from the side approached. On withdrawing the N pole the induced current is in the opposite direction, viz. *clockwise.* On inserting the S pole the induced current is *clockwise* : it is *counter-clockwise* when the S pole is withdrawn. We are, of course, speaking of the conventional current direction, not the direction of the electronic current. It can also be shown that the more quickly the magnet is moved the greater is the deflection and, therefore, the induced current.

From the preceding we learn that when the north pole is inserted the induced current is counterclockwise, that is, it has such a direction that the face of the coil approached is a north face, *which, therefore, tends to oppose the motion of the magnet.* When the north pole is withdrawn the induced current has such a direction that this face is a south face, which, therefore, *tends to draw the magnet back again*, and so on. Hence we have the important law known as **Lenz's Law**, viz. **the direction of the induced current (and E.M.F.) is such that it tends to oppose the motion or change which produces it.**

**74. Induction of Currents by Currents (Mutual Induction).**—This also can be illustrated by a simple experiment :—

In Fig. 56 *AB* diagrammatically represents a *coil* of wire joined to a galvanometer ; it is referred to as the **secondary circuit.** *CD* represents a *coil* in series with a battery and key ; it is referred to as the **primary circuit.**

Now start a current in the primary in the direction *C* to *D* and a momentary deflection of the galvanometer will ensue, showing that a current is induced in the secondary in the direction *B* to *A*, *i.e.* opposite or **inverse** to the primary current; it should be noted that starting a current in the primary means **increasing** the magnetic lines in the secondary, for the magnetic lines in the primary naturally reach over to the secondary circuit.

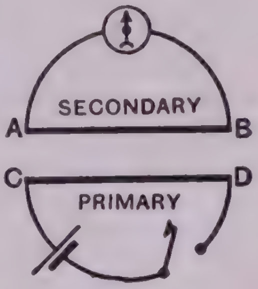


Fig. 56.

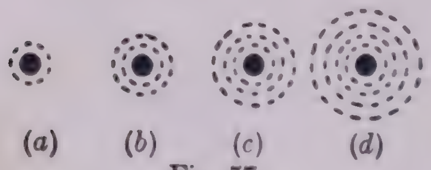
Switch off the primary current, and a momentary deflection of the galvanometer will follow, indicating a secondary current in the direction *A* to *B*, *i.e.* in the same direction as, or **direct** to, the primary current; it should be noted that stopping the primary current means **decreasing** the magnetic lines in the secondary.

Similarly, *increasing* the primary current or *moving it nearer* to the secondary circuit results in an *inverse* current; *decreasing* the primary current or *moving it away from* the secondary circuit results in a *direct* current.

From the preceding we arrive at another important law, viz. **an increase in the magnetic lines results in an induced inverse current, whilst a decrease in the magnetic lines results in an induced direct current** (Increase—Inverse : Decrease—Direct). This is quite in agreement with Lenz's Law. It should be noted that not only does the primary act upon the secondary, but also the secondary reacts upon the primary; hence these effects are known as **mutual induction.**

**75. Self Induction.**—We have already seen that the growth of a current means the growth of a magnetic field, also that an altering magnetic field near a conductor produces a current in the conductor; hence it is not surprising to find that this magnetic field which grows with the current *acts upon the current itself*; that is, it induces an E.M.F. in the original conductor acting in such a way as to oppose the growth of the current. Hence, when we start a current in a wire, the current produces a field, this reacts upon the current by setting up an *opposing E.M.F.* which delays its growth, the result being that it takes time to cause a current to reach its full value in the circuit. Similarly, when the current in a circuit is broken, the field is destroyed, and an induced current in the *same* direction as the one cut off is established (It is this latter induced current or *extra current* in the same direction as the one cut off which often causes a " spark " when a circuit is opened). Similar results obviously take place when a current in a conductor increases or decreases in strength. These effects are known as **self induction**.

It should be noted that the same rules apply here as in Art. 74. Thus, when we start or increase the current in a circuit (magnetic lines *increasing*) the induced E.M.F. is *inverse* : when we stop or decrease the current (magnetic lines *decreasing*) the induced current is *direct*.


(*a*) (*b*) (*c*) (*d*)
Fig. 57.

We can examine the preceding in a little more detail. When a current is started in a circuit the magnetic field does not come into complete existence *immediately*. It seems to begin, as it were, inside the wire and gradually extend outwards, as shown in Fig. 57: at (*a*) the current has just started and the field is small, at (*b*) it has grown, at (*c*) it has grown still more and so on, until finally it extends to a great distance. Now this field is being built up by energy taken from the current ; hence the current grows gradually, not reaching its final value until the field is fully established, and this is equivalent to an opposing pressure being induced in the wire. Similarly, when the current is switched off the magnetic field gradually collapses into the wire, giving up its energy as it does so ; thus the current does not immediately drop to zero, and the effect is equivalent to an induced direct current, *i.e.* one in the same direction as the current cut off. Similar effects will occur if the current in the circuit is merely increased or decreased in strength.

When a body is at rest it tends to remain at rest and when it is once in motion it tends to keep moving ; this property is referred to as *inertia*, and it is evidently greater the greater the weight of the body.

Now from the preceding it will be clear that self-induction behaves in a circuit like *inertia*, *e.g.* when we try to produce a current in a circuit this self-induction or inertia tends to choke the current back, and when we try to stop the current this self-induction tries to make it keep on.

**76. Inductance.**—The general name for the **property** exhibited by conductors of electricity dealt with in Arts. 74 and 75, *i.e.* the property of opposing the starting and stopping of a current or any change in the strength of a current, is **inductance.** In a straight wire the inductance is small; *it is much greater in a coil consisting of many turns, and it is considerably increased if the coil be wound upon an iron core.*

The unit of *inductance* is the **henry**: **a coil has an inductance (self inductance) of one henry if a current increasing at the rate of one ampere per second brings on an opposing E.M.F. of one volt.** Similarly **two coils have an inductance (mutual inductance) of one henry if a current increasing in one at the rate of one ampere per second induces an E.M.F. of one volt in the other.**

The henry may also be defined thus:—*If raising or lowering the pressure by one volt takes one second to produce a change of one ampere in the current, the inductance in the circuit is one henry.*

Inductances used in wireless are generally measured in **microhenries**: a microhenry is $\frac{1}{1000000}$ of a henry. Iron-core transformers used in wireless may have inductance values of several henries.

As in the case of capacity referred to in Art. 66, inductance can be expressed in terms of a length, a microhenry being expressed as an inductance of 10 metres.

**77. Another Glance at the Oscillatory Discharge of a Condenser.**—Referring again to the discharging condenser of Art. 70, it was mentioned that the discharge would be oscillatory if the resistance were not too great. Now in the circuit in question we have both capacity and inductance, for every wire possesses some inductance, and it can be shown that the limiting factor which determines whether the circuit will oscillate or not is as follows:—If the resistance be not greater than $\sqrt{\frac{L}{C}}$ where $L$ is the inductance in henries and $C$ is the capacity in farads, the discharge will be oscillatory: if the resistance be greater than this the discharge will not oscillate at all, but will simply leak across, never overshooting the mark, never reversing.

Again, in the case of the spring vibrating up and down (Art. 70), if a weight be suspended from the free end the vibrations will be found to be slower, *i.e.* the frequency will be decreased. Similarly the inductance in the circuit of the discharging condenser of Art. 70 adds, as it were, "weight" to the oscillating electric circuit and makes the vibrations slower: in other words *an increase in the inductance causes a decrease in the frequency, and a decrease in the inductance causes an increase in the frequency.*

Further, inductances as well as condensers are used as tuning devices in wireless receiving sets. From the preceding it will be surmised that, in tuning in a receiving set by means of an inductance, an increase in the inductance tunes the set to a lower frequency and, as will be seen later, this means to a greater wave length: similarly a decrease in the inductance tunes the set to a shorter wave length. Tuning by inductances and capacities is however dealt with in subsequent chapters.

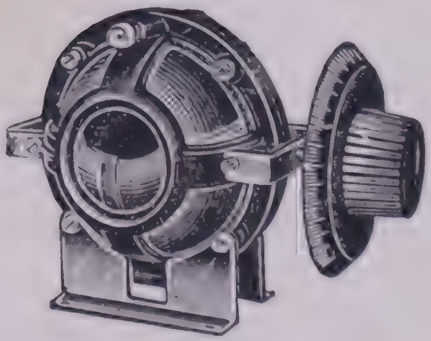


Fig. 58.

**78. Inductance Coils in Practice.**—There are many different types of inductance coils used in wireless, each having certain features making it specially suited for particular cases.

The **variometer** (Fig. 58) consists of an outer fixed coil of insulated wire known as the *stator*, inside which is another coil of insulated wire capable of rotation and known as the *rotor*. One end of the stator wire is connected to one end of the rotor wire, the other end of the stator wire and the other end of the rotor wire being joined to the two terminals of the variometer; the two coils are thus in series. Rotating the inner coil varies the inductance.

In some variometers the coils are wound on short cylinders of cardboard or vulcanite. In the best types, however, the rotor and stator are ball shaped, thus resulting in the greatest inductive "coupling," as it is termed, between the two coils.

The **sliding inductance** (Fig. 59) consists of a single layer of enamelled copper wire wound on an insulating tube, the turns being so spaced that they do not touch each other. Sliding contacts *S* can be moved to and fro along two brass sliding rails *B*, thus making contact with any desired turn of wire and varying the length of the coil being used, *i.e* varying the inductance. The enamel is of course removed from the wire immediately beneath the sliding rails.

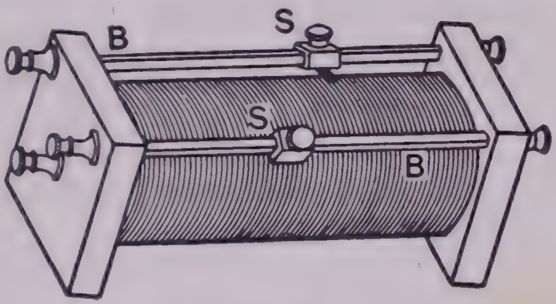


Fig. 59.

The **tapped inductance** is shown in principle in Fig. 145, page 165. It consists of a coil of insulated copper wire, but at intervals tappings are taken from it to studs, connection to the latter being made by means of rotating switch arms. It is usual to have two sets of studs as shown, tappings being taken at every ten turns, say, to one set of studs for coarse tuning, and from every turn to the other set of studs for fine tuning. By moving the switch arms the length of coil in use, and therefore the inductance, is varied.

The **loose coupler inductance** utilises the principle of mutual induction (Art. 74). It consists of two coils separate from each other, but one capable of sliding inside the other. Frequently the larger or outer coil is also fitted as a sliding inductance, and the smaller or inner coil as a tapped inductance, in order to secure further scope for variation of the inductance. The usual method of using such a loose coupler in a receiving set is to join the outer (or primary) coil to the aerial and earth and the inner (or secondary) coil to the detecting circuit (crystal or valve): this will be seen, however, in later chapters.

The **vario-coupler inductance** is a modification of the above. It consists of a variometer in which rotor and stator are not joined in series, but are separate coils with separate terminals : frequently the stator is also tapped.

So far the inductances dealt with have been single-layer coils. Sometimes a number of layers are required, in which case **pile wound inductances** are employed, all the layers being wound on the tube at the same time. (It would *not* do to wind one layer say, from right to left and then to wind the next layer back from left to right, and so on). Fig. 60 gives the principle of a three-layer pile winding, the numbers giving the order of the turns in winding.

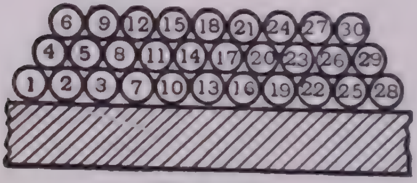


Fig. 60.

Every inductance coil possesses, of course, a certain amount of capacity, but it is well to keep this as small as possible, leaving all capacity to the aerial circuit and the condensers. There is no advantage whatever in having capacity all over the place, and there is certainly a decided drawback : *capacity and inductance should be kept as distinct and separate as possible for wireless installations.* It is for that reason—low capacity—that special windings are resorted to for the best inductance coils. Increasing the distance between the various turns of wire reduces the capacity, but this also decreases the inductance, and a compromise must be made. The too liberal use of wax or varnish must be avoided, as this increases the capacity : some must be used to render certain types of coils more rigid and robust, so again a compromise must be made.

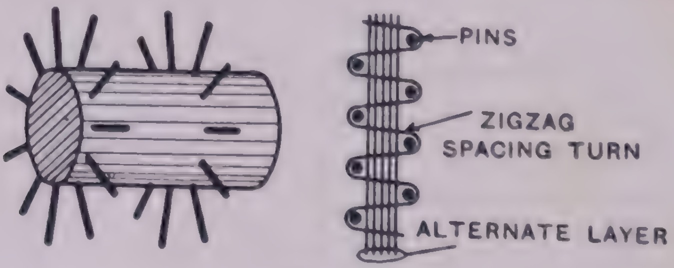


Fig. 61.

"Air spaced coils" are, however, to be preferred where possible. Various forms of special windings are indicated below.

The **lattice inductance coil** (Fig. 61) is made by winding a zig-zag turn round a number of pegs in a former. On the completion of this, a single layer of wire is wound round the former, then another zig-zag turn, and so on. Finally the coil is slightly soaked in melted paraffin wax and the pins and former removed.

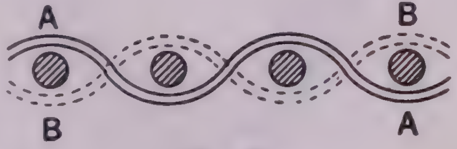


Fig. 62.

Fig. 62 depicts a modification which is largely used by wireless experimenters (incidentally, these windings are often referred to as **basket coil windings**). The former consists of an odd number of spokes—generally 9 or 11 or 13—radiating from a hub after the manner of one of the two radiating sets of spokes in Fig. 61. In *single basket winding* the wire passes on alternate sides of the spokes as shown in Fig. 62. In *double basket winding* the wire passes on one side of two spokes, then crosses over and passes on the other side of the next two spokes, and so on (Fig. 63), the crossing points being alternate as shown in the figure: when four turns are completed every pair of spokes has a pair of wires on the outside and another pair crossing between them.

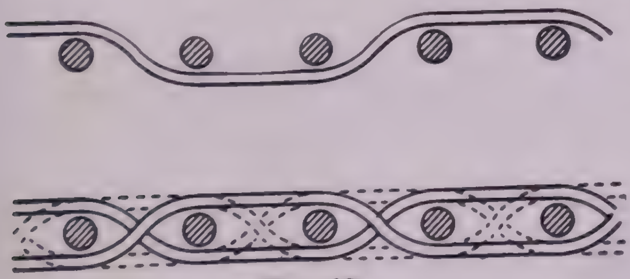


Fig. 63.

The student will come across other coil winding names in his reading, *e.g.* **honeycomb**, **duo-lateral**, etc., etc., the former referring to a winding in which the turns in one layer are over the turns in the layer below, and the latter to one in which the turns in one layer are over the spaces between the turns in the layer below.

The **plug-in inductance coil** is the form in which the preceding coils are generally arranged in practice. The ends of the coil are brought to a plug and socket mounted in a piece of ebonite attached to the coil : the receiving set is fitted with a corresponding plug and socket so that the coil can be "plugged in." Fig. 64 shows the general appearance of a plug-in coil and Fig. 65 of a simple coil holder. A coil similar to the preceding but tapped so that four different inductances can be used is shown in Fig. 66. A variable coupling—utilising the property of mutual induction—can be used with two plug-

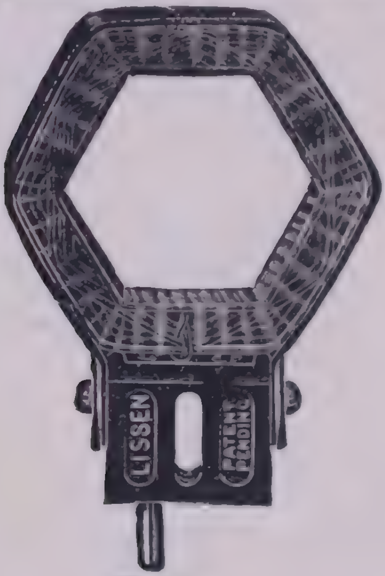


Fig. 64.

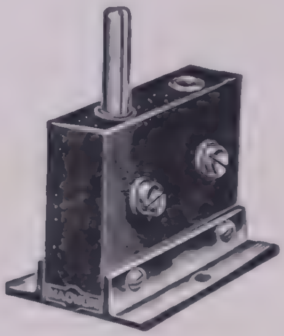


Fig. 65.

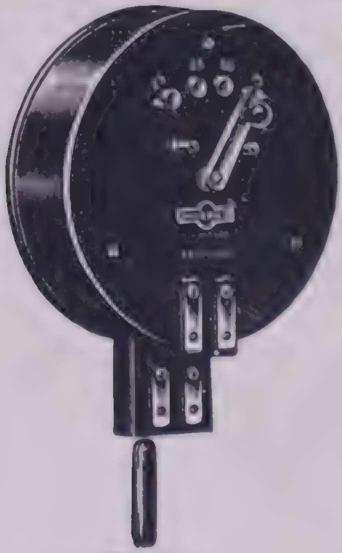


Fig. 66.

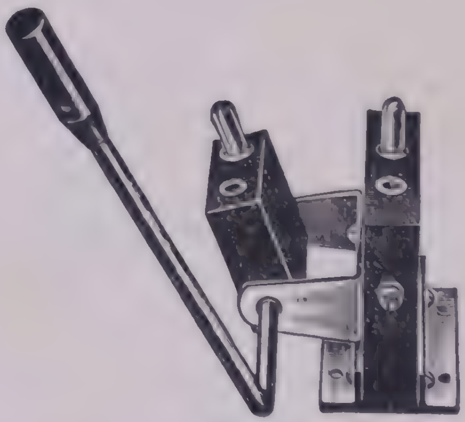


Fig. 67.

in coils and the holder shown in Fig. 67 : the holder carries two coils (the primary and secondary) and one is pivoted as indicated, so that the distance between the coils can be varied. Another type of holder is arranged to take three coils, the outer two being pivoted : such a holder (and three coils) is often used in valve receiving sets.

Coils are numbered by the makers to indicate their suitability for particular wave lengths : this however is dealt with in Chapter X.

**79. The Induction Coil.**—The **induction coil** is an application of the principles of mutual induction, consisting of an apparatus for changing a low P.D. between the terminals of a primary coil into a high P.D. between the terminals of a secondary coil.

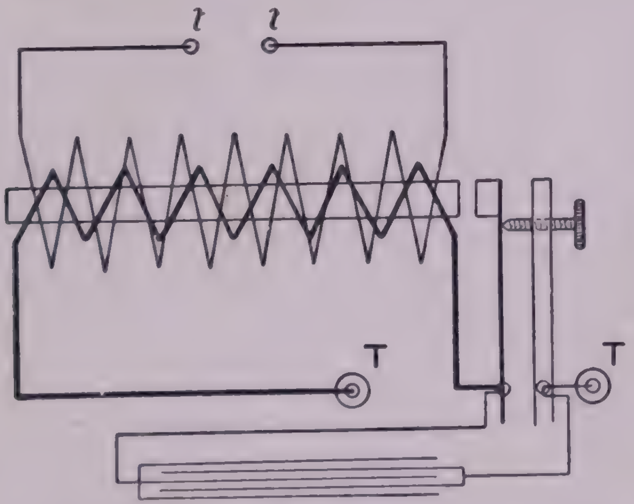


Fig. 68.

The construction of the apparatus is shown in Fig. 68. Round an inner core composed of a bundle of soft iron wire is wound a coil consisting of a few turns of very stout wire, forming the **primary** of the coil ; this is in series with a " break " consisting of a spring touching a contact screw, the spring carrying at its upper end a small piece of soft iron, which is attracted by the core of the coil when current flows through the primary and magnetises the core, and falls back when the current ceases and the core becomes demagnetised. Hence, on attaching the battery, an intermittent current passes through the coil, the frequency of the interruptions depending upon the strength and inertia of the spring.

Surrounding the primary, but insulated from it with great care, is a coil consisting of a very large number of turns of very fine wire forming the **secondary**. The ends of this wire are led out of the casing and are attached to terminals on the top of the coil, and usually when the coil is working the secondary circuit is complete, except for a gap, across which it is desired to cause sparks to leap.

Up to this stage in the construction the action may be briefly explained as follows. When the primary current passes (1) *an induced inverse current is developed in the secondary*, and (2) the core is magnetised, the soft iron head and spring are attracted and the primary circuit is broken; when the primary current ceases (1) *an induced direct current is developed in the secondary*, and (2) the core is demagnetised, the spring falls back against the screw, the primary current again starts and the actions are repeated. It follows from this that so long as the primary current is made and broken so long will induced currents in opposite directions circulate in the secondary.

In practice, matters are not so simple as indicated above, owing to the self-induction of the primary coil itself. It is not necessary to go into details in this book. We will simply say that in practice a condenser is put in the primary circuit as indicated (Fig. 68) and the secondary induced currents are then mainly those which occur when the primary is broken.

**80. The Telephone—Receivers and Transmitters.**—There are two pieces of apparatus which will be briefly considered here, viz. the **Bell magneto telephone** (to give it its original name) which is used as a **receiver** and the **microphone** which is used as a **transmitter**.

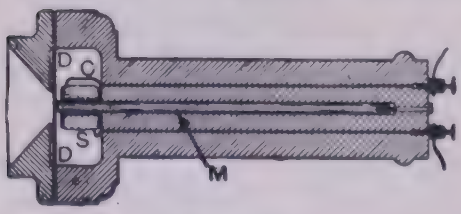


Fig. 69.

Originally the Bell magneto telephone was used both as a transmitter and as a receiver, and its action in this double sense will first be explained. A section through the instrument is shown in Fig. 69. Here *M* is a permanent magnet carrying at one end a piece of soft iron *S*. This forms the core for a coil *C* which has leads to the two terminals of the instrument. In front of *S* is fixed a very thin soft iron disc *DD*. The main body of the instrument is of ebonite.

The action is as follows :—When a person speaks into the orifice the waves of sound cause the disc to vibrate, and as it moves to and from the soft iron core the distribution of the lines of force in the vicinity of the coil is altered. A current is, therefore, induced in *C*, the E.M.F. of which changes according to the rate at which the number of lines of force passing through *C* changes, *i.e.* according to the vibrations of the disc and therefore according to the words spoken. At the distant end of the line is a similar instrument to act as a receiver, the terminals of which are directly connected to those at the transmitter, so that as the currents generated in *C* vary with the sound, so also do those received at the distant station.

The reverse operation now takes place at the receiver. The current in its coils varying, the field in the neighbourhood varies, and the soft iron piece of the receiver attracts with varying strengths the vibrating disc immediately in front of it. Thus the disc of the receiver copies the movements of the disc of the transmitter, and these movements of the receiving disc being transferred to the air, the sound also is reproduced.

From the above it will be seen that two of these instruments without any battery can be used as a simple telephone circuit.

In modern practice the Bell telephone is used only as a receiver, and Fig. 70 depicts the construction of one present type of instrument used in wireless reception. *M* is the permanent cobalt-steel magnet; as a rule it is in the form of a ring and is fitted with soft iron pole pieces *P* on which the coils *C* are wound. *D* is a stalloy diaphragm. The containing case is of ebonite or non-resonant composition. The wires leading from the coils to the terminals are not shown in the figure.

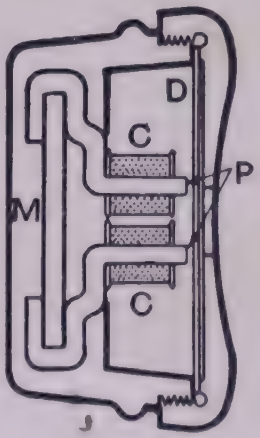


Fig. 70.

**A loud speaker** is simply a telephone receiver specially constructed to permit of a large displacement of the diaphragm and to produce a big volume of sound. One type is indicated diagrammatically in Fig. 71. The current from the set passes through a primary coil, whilst a secondary coil is connected to a movable coil attached to the diaphragm. The movable coil is in the field of an electromagnet which is excited by a small battery. The primary and secondary form what is called a step-down transformer (Art. 87). The varying current from the set causes corresponding changes in the position of the moving coil, and the moving diaphragm produces the sound as in the case above.

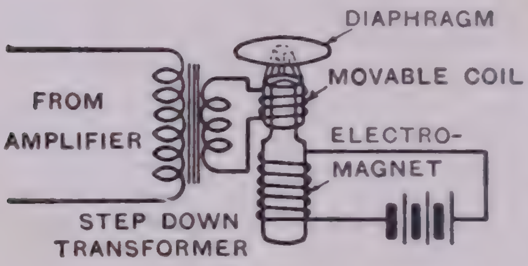


Fig. 71.

The principle of the modern microphone transmitter is as follows :—If sound waves be produced near a loose electrical contact, notably in the case of one or more sticks of carbon supported lightly by two fixed blocks of carbon, the vibrations cause the resistance of the point of contact to vary enormously, and thus a battery in series with the loose carbons will send a varying current to line as long as the sound vibrations continue ; this varying current passing through a telephone receiver will actuate it in the manner described above, so that the sound is reproduced. Such an arrangement is shown diagrammatically in Fig. 72.

Fig. 73 shows the details of such a transmitter. A number of granules of carbon (*A*) are enclosed in a chamber, the back and front of which are carbon discs. The back disc *E* is joined to the terminal *B* : the front disc is attached to the diaphragm *C*, which is held by its rim in the metal case *D* ; *D* is insulated from the terminal *B*. The line is connected to *B* and to *D*, the necessary battery being included in the circuit. The battery can, therefore, send a current to *B*, to *E*, through the carbon granules *A* (between which a large number of loose contacts exist), and hence to *C*, to *D*, and back to the line and battery.

In practice the microphone is not directly connected to the line as in Fig. 72, but to the primary of an induction coil, the secondary of which is connected to the line; by this device the E.M.F. is magnified in the ratio of the secondary to the primary turns (Art. 87), and thus can overcome a high resistance in the line.

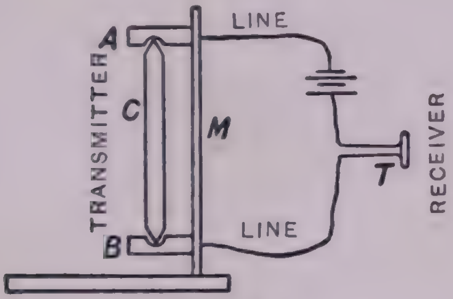


Fig. 72.

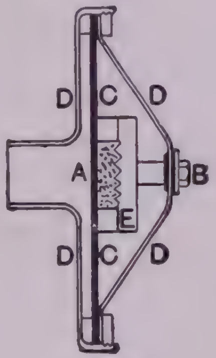


Fig. 73.

The carbon microphone is used in wireless telephony, but as large currents are being dealt with,and even small distortion is fatal to the transmission of music, many improvements in microphone design have been made, and the whole constructed on a larger scale. As, however, the principle is the same in all cases, viz. the variation of a current brought about by the sound waves, they need not be described here.

**81. The Three Properties of an Electric Circuit.**—Before proceeding further, it would be well for the student to recall the three important properties of an electric circuit, viz. **resistance, capacity,** and **inductance.** It should be noted also that capacity and inductance are only of importance when the current in the circuit is varying in strength: with a constant current circuit, except at starting and stopping, we need only trouble about resistance.

In wireless, we deal with very rapidly varying currents—high frequency oscillations as they are termed—and capacity and inductance play a vitally important part. Resistance is always cut down as low as possible: it is rarely any good and invariably a nuisance. But even *very small* capacities and *very small* inductances mean a great deal to the wireless engineer, the experimenter, and even the " listener in." The power station engineer does not worry about a micro-microfarad or a microhenry : it would take some millions of his volts to drive, to him, a paltry ampere through the former, and it would take about three thousand of his amperes to set up a meagre pressure of a volt across the latter, so to him they are nonentities : but the wireless man must be ever on the alert for these small capacities and inductances. Capacity and inductance are essentials in wireless, but if they are " strays," however small, and appear on the scene at other places than where they are wanted, efficiencies will suffer. The student will realise the truth of this as his studies proceed.

# CHAPTER VI.

## A FEW FACTS ABOUT ALTERNATING CURRENTS.

82. **Alternating Currents and Pressures.**—The subject of alternating currents and alternating pressures always presents a certain difficulty to beginners, but at this stage it is only necessary to draw attention to one or two elementary principles and one or two essential terms which the student will encounter in his reading. No attempt will be made, therefore, to go into details or to enter into the mathematics usually associated with this subject.

The current derived from an ordinary cell or battery is what is known as a continuous current; that is to say, so long as the external circuit is closed, the current flows continuously in one direction. There are, however, currents which do not flow in this way but periodically reverse, flowing for a certain time in one direction and then reversing, flowing for another period of time in the opposite direction; such are called **alternating currents**. Referring to a hydraulic analogy, we may say continuous currents correspond to the flow of water along a line of pipes fed by a force pump, while on the other hand alternating currents correspond to the flow of water along pipes leading at one time from a force pump, and at another from a suction pump, the water being alternately forced into the pipes and then sucked from them.

When an alternating current is produced in a circuit the E.M.F. or pressure continuously changes; it rises to a maximum, then dies away to zero, being followed immediately by a reversed E.M.F., which also rises to a maximum and dies away to zero, and so on. If, now, at any particular moment the E.M.F. is at a certain value, and is just going to commence a certain set of variations, then the time which elapses between this instant and the instant when the E.M.F. has the same value and is going to commence an identical set of variations, is called the **period** of the current, and the number of periods accomplished in one second is called the **frequency**, the maximum value of the E.M.F. being called the **amplitude**. The exact meaning of these terms can best be seen from Fig. 74.

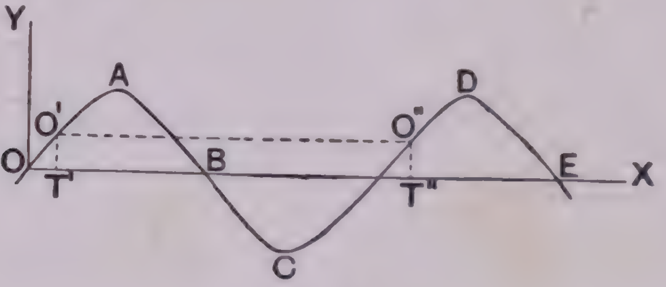


Fig. 74.

Suppose time is measured along $OX$, and E.M.F. along $OY$. Then for a certain alternating current the curve showing the relation between the variation of voltage and time will be $OABCDE$. . . . Volts measured above $OX$ correspond to the direct E.M.F.; volts measured below $OX$ correspond to the reversed E.M.F. We may select any arbitrary point on the curve, such as $O'$; then, counting time from the instant when the E.M.F. was last zero, we see that at time $OT'$, the voltage was $O'\,T'$. Drawing $O'\,O''$ parallel to $OX$, we also see that at time $OT''$ the voltage was $O''T'' = O'T'$, and since when the voltage was $O'T'$ and $O''T''$ the same set of variations was commencing, we see that by definition $T'T''$ represents what we have called the *period*. Evidently the period would also be represented by $BE$. The *frequency* would then be the number of such time intervals as $T'T''$ contained in one second, and the volts corresponding to the maximum points $A$, $C$, and $D$, etc., would be the *amplitude*. From $O$ to $B$ is frequently referred to as an *alternation*, and from $B$ to $E$ as a *cycle*.

The frequencies in common use are—for electric railways 25 per second, and for lighting and power 50 per second. Frequencies are spoken of as being " high " or " low," but it must be remembered that such terms are purely relative. Thus 100 cycles per second might be called a low frequency as compared with one of 10,000 cycles per second, which would be called a high frequency. When the frequency rises to the order of 100,000 per second the current is generally called a **high frequency oscillatory current** or a " high frequency electric oscillation." In wireless we really apply alternating current to the transmitting aerial in order that it may radiate energy which passes along in the form of aether waves—wireless waves—and for this to take place *very high frequency oscillatory current* is essential; in practice, this frequency may be of the order one million cycles or more per second.

83. **Lagging and Leading Currents.**—As already indicated, the current accompanying a periodic electromotive force is of course also periodic; it rises to a maximum, falls to zero, reverses, rises to a maximum, falls to zero, and so on; and the frequency of the E.M.F. is also that of the current. There is, however, this important difference. The alternating current does not always keep time with the alternating electromotive force, so that the maximum current is not obtained when the value of the E.M.F. is a maximum, but occurs a little after it or a little before it according to the nature of the circuit.

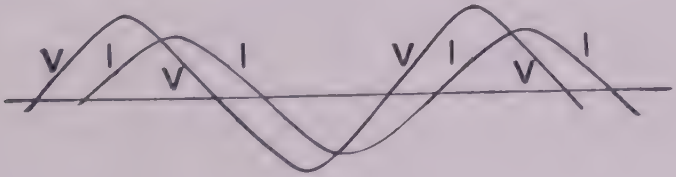


Fig. 75.

If an inductive resistance is included in the circuit the maximum current will occur *after* the E.M.F. has reached its maximum value: the current is then said to **lag**. On the other hand, if there is capacity in the circuit the maximum current will occur *before* the E.M.F. has reached its maximum value: the current is then said to **lead**. These terms may readily be understood from Fig. 75 which shows a curve of alternating pressure *V*, *V*, *V* . . . and the curve of alternating current $I, I, I$ . . . with inductance in the circuit, and it will be seen that the current lags behind the pressure.

The lag (and lead) are best expressed in terms of the period of the alternating current and pressure. Thus if the maximum current occurred $\frac{1}{8}$ period after the maximum pressure, we should say that the lag was $\frac{1}{8}$ of a period. If the frequency were 50 cycles per second the lag would also be said to be $\frac{1}{8}$ of $\frac{1}{50}$, *i.e.* $\frac{1}{400}$ second. Taking a complete cycle as 360°, then the lag could also be expressed as $\frac{1}{8}$ of 360°, *i.e.* 45°.

The lag and lead are sometimes spoken of as the **phase difference**. It is possible so to adjust the capacity (which causes lead) and the inductance (which causes lag) in an alternating current circuit that there is neither lag nor lead, and this is an important case in wireless circuits : in such a case we say that the current is *in phase* with the pressure.

**84. Measurement of Alternating Currents and Pressures.**—Since an alternating current is constantly changing its strength, and constantly reversing its direction, it cannot be measured by the decomposition of a solution of silver nitrate or by the deflection of a compass needle as can be done with a continuous current, for the effect of the alternating current on the solution or on the needle when it is flowing one way would be undone by the effect when it is flowing the other way. As, however, the heating effect of a current does not depend on the direction in which it is flowing, this effect can be used for the purpose. We therefore base our measurements on the heating effect and measure alternating currents and pressures in what are called **virtual amperes** and **virtual volts** respectively, which are defined as follows :—

*A virtual ampere is one which will produce the same heat in a resistance as a steady current of one ampere will produce in the same time*, and it can be shown that *the virtual value of the current is* ·707 × *the maximum current.*

Similarly, *a virtual volt is one which, when applied to the ends of a resistance, results in the same heating effect as in the case of a steady pressure of one volt applied for the same time*, and *the virtual value of the pressure is* ·707 × *the maximum pressure.*

Virtual values are often spoken of as "the square root of the mean square" or " root mean square " or " R.M.S. " values.

**85. Flow of Alternating Current through a Condenser.**—In wireless and in alternating current work in general the student will often come across the statement "a continuous current will not flow through a condenser, but an alternating current will": in fact in valve receiving sets condensers are used to prevent the flow of continuous current in certain paths, whilst permitting alternating current to "flow" in these same paths. It is essential that the student should understand the exact meaning of such a statement.

Imagine a condenser joined to a battery which of course gives a continuous current. There is certainly a momentary flow of electrons from the negative pole of the battery to the condenser plate joined to it until the two are at the same potential, and a similar flow of electrons from the other condenser plate (leaving it with an excess of positive ions) to the positive pole of the battery until their potentials are the same. The condenser is charged, but there the matter ends; the dielectric of the condenser is an insulator and breaks the continuity of the circuit, so that nothing further happens unless the dielectric is ruptured. All this will be apparent from what has been said in Chapter V.

Now consider, for convenience, the alternating current circuit shown in Fig. 76 where *P* and *Q* are two condensers, *L* a lamp, and *M* an alternator (a machine or generator for producing alternating current). During the first half cycle of the alternating current, electrons rush, say, from *M* to *A* (making *A* negatively charged), an equal number rush from *B* to *C* (making *B* positive and *C* negative) and an equal number rush from *D* to *M* (making *D* positive). During this half cycle, therefore, there has been a flow of electrons through the lamp from *B* to *C*. Clearly, during the next half cycle the flow of electrons will again occur, but in the opposite direction, viz. *M* to *D*, *C* to *B*, and *A* to *M*: during this half cycle, therefore, there has been a flow of electrons through the lamp from *C* to *B*. Thus although there is not a conducting road right round the whole circuit, the movement of electrons

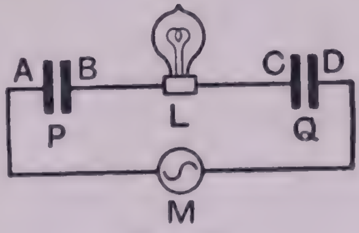


Fig. 76.

(*i.e.* the flow of current) to and fro in the alternator part of the circuit causes a corresponding movement of electrons (*i.e.* flow of current) to and fro in the part *BC*, and the lamp lights up. In a word the condensers do not stop the " action " or the " effect " of the alternating current in the part *BC* ; hence the statement that an alternating current can flow through a condenser. It is a loose but brief and convenient way of stating what happens.

**86. The Choking or Throttling Effect of an Inductance on an Alternating Current.**—In wireless and in alternating current work in general the student will also frequently come across the statement " an alternating current encounters considerably more opposition in flowing through a coil of wire, especially if wound on an iron core, than a continuous current does." In fact in all branches of electrical engineering it is customary to employ coils for the special purpose of preventing or choking back the flow of alternating current in some particular part of a circuit : such coils, which are specially made of low resistance and do not interfere with the flow of continuous current, are called **choke coils or chokes.**

The whole action of the choke coil depends of course on self induction. Imagine a coil consisting of a few turns of thick wire wound on an iron core : its resistance will be very small but its self induction may be large. If a continuous current be started through the coil the induced opposing E.M.F. in the coil will certainly delay its growth, but when the current has once reached its full strength the inductive effect ceases, and owing to the small resistance, a large current will be flowing. If an alternating current be sent through the coil, however, the inductive effect is for ever acting, opposing the growth of the current and also opposing the decay and reversal : the coil continually exerts an opposition effect on the changing current. In short, we might say that in the path of a rapidly altering current a choke coil acts like a very high resistance, while to a continuous current the resistance is practically negligible. This is because in the first case the inductive action is all important, while in the second case the inductive action scarcely matters at all.

An instructive experiment to illustrate the preceding is as follows :—Arrange two wires in parallel, one having a high resistance and formed of straight wire and having a red lamp in series with it, and the other wire of low resistance but coiled up into a close spiral and having a green lamp in series with it. If we supply a *continuous* current to the system the *green* lamp only will light, but if we supply an *alternating* current to the system the *red* lamp only will light.

There are many types of chokes on the market, for details of which the makers' catalogues should be consulted. The essential point in the construction of most of them is that they are coils of low resistance, wound on iron, so as to have a marked inductance : the essential point in their action is that owing to their low resistance a continuous current readily flows through them, whilst owing to their large self induction the passage through them of an alternating current which is always changing is considerably opposed. It must be borne in mind that inductive effects only last while a change is taking place.

**87. Transformers.**—A **transformer** is a device in which the inductive action of one circuit on another—a primary coil on a secondary coil—is employed in practice. The induction coil of Art. 79 is really a transformer. The primary and secondary coils of the induction coil are wound upon an iron core, but are quite distinct and separate from each other. A make and break is inserted in the primary. Every time the primary current is made an inverse pressure is induced in the secondary, and every time the primary current is broken a direct pressure is induced in the secondary. Further, the secondary coil has a large number of turns compared with the primary coil, and the pressure induced in the secondary is, in consequence, larger than the pressure applied to the primary, the current induced in the secondary being, of course, proportionally less than that put into the primary.

Commercial transformers, then, consist of two coils—a primary *AA* (Fig. 77) and a secondary *BB*—quite separate from each other and invariably wound upon an iron core, so as to increase the magnetic lines and the inductive effect. They are intended to work with alternating currents, so that the primary current is constantly rising and falling and being reversed ; hence inductive effects on the secondary are always occurring and no mechanical make and break of the primary is necessary, as in the case of the induction coil. The varying current in the primary produces a varying magnetisation of the iron core and varying magnetic lines in the secondary, which results in varying induced pressures in the secondary. The induced pressure in the secondary also depends on the number of turns of wire in it, and in fact we practically have the relation :—

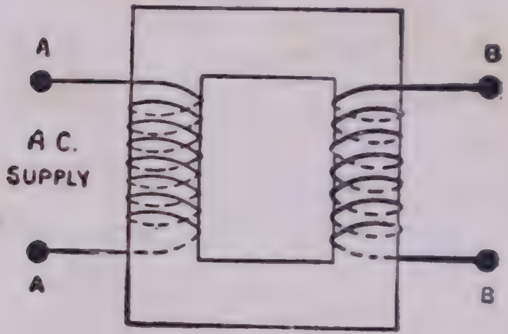


Fig. 77.

$$\frac{\text{Pressure in secondary}}{\text{Pressure in primary}} = \frac{\text{Number of turns in secondary}}{\text{Number of turns in primary}}.$$

Thus if the secondary has 10 times the number of turns that the primary has, the pressure induced in the secondary is roughly 10 times the pressure applied to the primary, *i.e.* the ratio of transformation is roughly 10 : 1. This is, of course, neglecting all losses of energy in the transformer. Further, since we cannot gain energy by the transformation it follows that the current in the secondary must be proportionally less *i.e.* (approximately).

$$\frac{\text{Current in secondary}}{\text{Current in primary}} = \frac{\text{Number of turns in primary}}{\text{Number of turns in secondary}}.$$

Transformers are used commercially in two ways, viz. :—

(1) *Step-up Transformers.*—In these the alternating current in the primary induces alternating current in the secondary at a higher pressure, i.e. *they raise the pressure, and for this the secondary has more turns than the primary.*

(2) *Step-down Transformers.*—In these the alternating current in the primary induces alternating current in the secondary at a less pressure, *i.e. they lower the pressure, and for this the secondary has fewer turns than the primary.*

The above is only an elementary treatment of the transformer, and more rigid investigation is beyond the scope of this book. But it may be noted that some of the losses which must be taken into account in an exact treatment are :—

(1) The losses in the primary and secondary coils due to the heating effect of the current.

(2) The losses due to magnetic leakage; that is, due to the fact that all the magnetic lines produced by the primary current do not pass through the secondary circuit.

(3) The losses due to what are known as *eddy currents* and *hysteresis* in the iron core.

The alternating primary current not only acts inductively on the secondary circuit but it also acts inductively on the iron core, setting up currents in it; these are known as **eddy currents** or **Foucault currents**, and they naturally mean a waste of energy. To reduce them the core must be subdivided *laterally* (*e.g.* built up of a bundle of thin plates or fine iron wire), for this is the direction in which these currents tend to flow. The magnetic lines due to the primary current run *longitudinally*, so that the iron is, as it must be, still continuous in this direction. A core subdivided in this way is called a *laminated* core.

Now consider a bar of iron in a solenoid through which a current is passing; the bar is therefore magnetised. If the current be gradually reduced to zero the magnetism decreases, but when the current is zero some magnetism still remains, and it requires a certain current in the opposite direction (which of course tends to magnetise in the opposite direction) to wipe out the magnetism. In fact the changes in magetism lag behind the changes in current. This becomes pronounced if the current be first increased to a maximum, then reduced to zero, then increased to a maximum in the opposite direction, then reduced to zero and so on.

The effect which is brought into prominence in the above, viz. that the rise in magnetism is not quite similar to the fall in magnetism, that when the current is brought to zero, some magnetism still remains, that in fact the changes in magnetism lag behind the changes in current, is called **hysteresis**, and it really represents a loss of energy caused by the changing magnetic condition.

Turning now to the case of the alternating current circulating in the primary coil of the transformer, it will be clear that the magnetism of the core is constantly rising and falling and being reversed : thus hysteresis loss occurs at each cycle and naturally becomes pronounced if the frequency is high. To keep this loss down as much as possible special care must be taken in selecting the iron for the transformer cores.

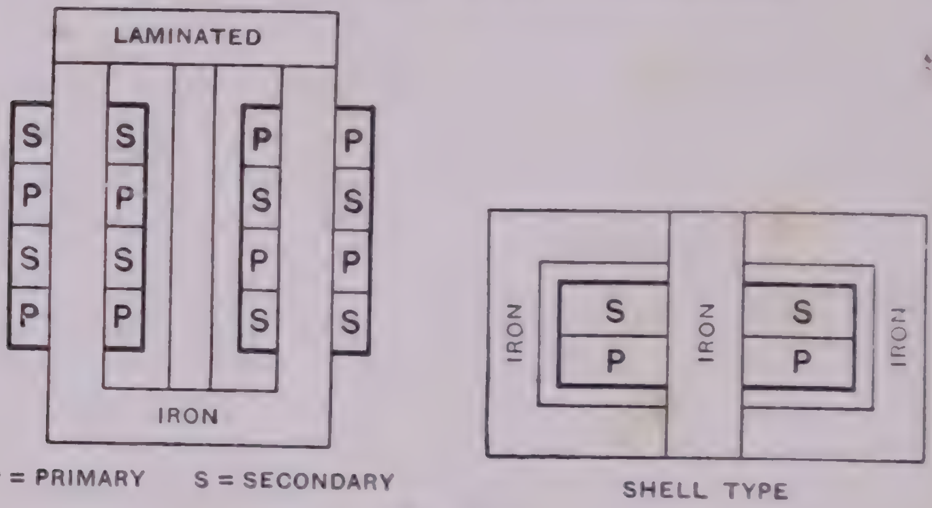


Fig. 78.

The construction of two forms of modern **closed magnetic circuit transformers** will be gathered from Fig. 78. In older types, the iron core, like that of an induction coil, did not pass completely round to form a closed iron circuit for the magnetic lines : such were called **open magnetic circuit transformers.** The figure on the left depicts what is called a **core type** transformer, whilst that on the right is called a **shell type** transformer.

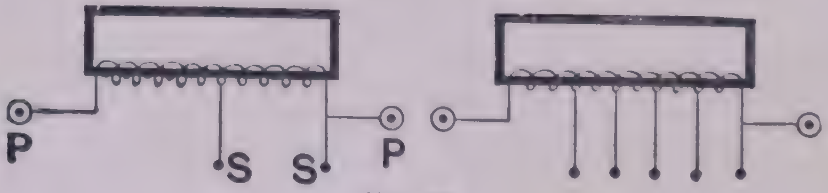


Fig. 79.

The principle of what is called an **auto-transformer** is shown in Fig. 79. As will be gathered from the figure, the "primary" winding is mounted on a laminated iron core, but instead of a separate secondary coil, a portion of the turns is tapped off to form the "secondary" circuit. In this way a secondary pressure is obtained lower than the primary pressure, practically in the ratio of the number of turns tapped off to the total number in the winding.

In wireless the student mainly encounters two types of transformers, one used for high frequency work and referred to as a **high frequency transformer**, the other used for low frequency work and referred to as a **low frequency transformer**, an essential difference between them being that *low frequency transformers are provided with iron cores but high frequency transformers are not.* Every transformer with an iron core experiences a waste of energy due to eddy currents and hysteresis, and this waste increases with the frequency. If the frequency is not too high, *e.g.* if it is what is termed in wireless "audio-frequency" (Chapter VII.), this loss can be tolerated, for the advantages gained by the use of the iron—increased magnetic lines and greater inductive effects—will more than compensate. If, however, the frequency is high, say of the order of a million per second, the loss per cycle multiplies up to such an extent that it cannot be put up with; hence high frequency transformers must not have iron cores: air cores are best, for air shows neither hysteresis nor eddy currents.

As a matter of fact iron in a high frequency transformer in wireless receivers makes a hopeless mess of things: it wastes energy, it does not get properly magnetised, it tends to cut down the primary oscillations, and it distorts them, finally distorting the speech and music heard in the telephones.

Fig. 80 shows the **RI low frequency transformer** made by the Radio Instruments Ltd. The soft iron core is rectangular and surrounds the coils; it is made up of thin soft iron laminations. The **McMichael high frequency transformer** is depicted in Fig. 81. High frequency transformers are often of the plug-in type, *i.e.* the primary and secondary terminals are connected to four legs which are plugged into sockets on the receiver. In Fig. 81 the two coils are wound in grooves on the outer surface of an ebonite cylinder. There are, however, many other makes of transformers suitable for mounting in different ways on wireless receiving sets; for details of these the makers' catalogues should be consulted. Further, as will be seen later, the principle of the auto-transformer is largely used in wireless circuits.

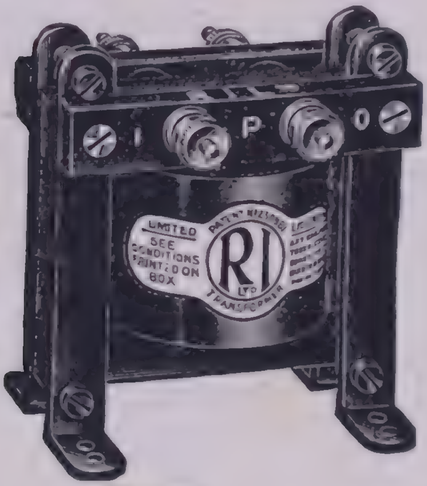


Fig. 80.

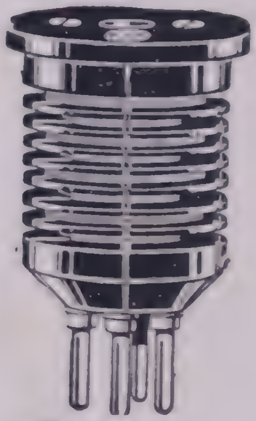


Fig. 81.

**88. Impedance, Reactance, Resistance, Resonance.**—In the case of continuous currents, Ohm's law leads to the fact (readily verified by experiment) that the current $I$ (amperes) which a pressure $E$ (volts) drives through a resistance $R$ (ohms) is given by :—

$$\text{Current} = \frac{\text{Pressure}}{\text{Resistance}}, \text{ or } I = \frac{E}{R}, \text{ or Amperes} = \frac{\text{Volts}}{\text{Ohms}}.$$

The law for alternating currents, corresponding to Ohm's law for continuous currents, is expressed thus :—

$$\text{Current} = \frac{\text{Pressure}}{\text{Impedance}},$$

where **impedance** is to an alternating current what resistance is to a continuous current. In fact for the purpose of the beginner we may regard impedance as the effective resistance encountered by an alternating current. Now it has been indicated that there are three main properties of an electric circuit, viz. resistance, inductance, and capacity, and that whilst with continuous currents all that need be troubled about is the resistance, with alternating currents all three factors—

resistance, inductance, and capacity—exert an influence (and of course so also does the frequency) and all these factors must be taken into account. The reader will therefore be prepared for the statement that the impedance encountered by an alternating current—the factor in the denominator of the expression given above—involves the resistance, inductance, and capacity of the circuit, and the frequency of the alternating pressure and current.

For simplicity we will consider first a circuit containing resistance and inductance but no capacity; it can be shown that:—

$$\text{Impedance} = \sqrt{(\text{Resistance})^2 + (\text{Reactance})^2}$$

and that:—

$$\text{Reactance} = 6f\text{L (approximately)},$$

where $f$ is the frequency and $L$ the inductance of the circuit. If, further, we assume the resistance to be so small that it can be neglected, the whole impedance becomes equal to the reactance, and we have for the current:—

$$\text{Current} = \frac{\text{Pressure}}{\text{Impedance}},\ i.e.\ I = \frac{E}{6fL}.$$

It has been stated that in an inductive circuit the current lags behind the pressure, and hence the reactance above is sometimes referred to as *positive reactance*: since its value is $6fL$, positive reactance evidently increases with the frequency.

Now consider a circuit with resistance and capacity but no inductance. In this case it can be shown that:—

$$\text{Reactance} = \frac{1}{6fC}\text{(approximately)},$$

where $C$ is the capacity of the circuit. If, again, we assume the resistance to be small and negligible, the whole impedance becomes equal to the reactance, and we have for the current:—

$$\text{Current} = \frac{\text{Pressure}}{\text{Impedance}},\ i.e.\ I = \frac{E}{\frac{1}{6fC}} = 6fCE.$$

It has been stated that in a capacity circuit, the current leads in front of the pressure, and hence the reactance above is sometimes referred to as *negative reactance* : since its value is $\frac{1}{6fC}$ it evidently decreases as the frequency increases.

Consider now a circuit with both inductance and capacity, and again for simplicity imagine the resistance so small as to be negligible. We have seen that the inductance causes lag of current and the capacity causes lead of current ; the lag really depends on the value of the positive reactance $6fL$ and the resistance, and the lead depends on the value of the negative reactance $\frac{1}{6fC}$ and the resistance. Clearly if these two reactance values are equal there will be neither lag nor lead : in other words, there will be neither lag nor lead if the frequency $f$ be so chosen that

$$6fL = \frac{1}{6fC} \quad \text{or } f^2 = \frac{1}{36LC}$$

$$\text{or } f = \frac{1}{6\sqrt{LC}}.$$

We arrive then at this fact :—If $L$ be the inductance of a circuit (in henries) and $C$ its capacity (in farads), and if an alternating current be sent through the circuit, there will be lag or lead of current according as to whether the positive reactance or the negative reactance is bigger, but if the frequency be so chosen that it is numerically equal to $\frac{1}{6\sqrt{LC}}$ there will be neither lag nor lead, and the impedance of the circuit, being made up only of the resistance (since the two reactances have cancelled), *is less than it is at any other frequency*, and the current will be big. Such a circuit is said to be **in resonance** : *resonant circuits are of importance in wireless.*

Some peculiar results happen if an alternating current circuit is in resonance. Consider for example a circuit $A$ of resistance 5 ohms and inductance 5 henries in series with a circuit $B$ of resistance 10 ohms and capacity 200 microfarads. The frequency of this circuit calculated from the relation $f = \frac{1}{6\sqrt{LC}}$ is about 100. Now suppose an alternating pressure of

200 volts also at a frequency of 100 be applied to this circuit. On working out the values of the pressures at the ends of $A$ and $B$, it will be found that although the applied pressure is only 200 volts, *really big pressures of nearly* 15,000 *volts exist at the ends of $A$ and $B$ respectively.*

As the student will see in the next chapter, in a wireless transmitting station we have a primary circuit in which a rapid alternating current of frequency $f$, say, is circulating. The secondary of this circuit consists of the transmitting aerial, involving inductance $L$ and capacity $C$. Now suppose the aerial inductance and capacity be varied until $\frac{1}{6\sqrt{LC}}$ has the same value as $f$. The circuits will then be *tuned to resonance*, as it is termed, the currents in the aerial will be in step or in phase with the E.M.F., and as the resistance of the aerial is small, such currents will be large. Further, as in the numerical example quoted above, there will be big pressures across the inductance and capacity circuit, *i.e.* between the top of the aerial and the earth. These large currents and pressures result in strong electric and magnetic fields, and, as will be seen later, both these effects lead to strong radiation from the aerial in the form of wireless waves.

From what has been said it will be clear that in order to make two circuits in tune with each other, the value of $LC$ for one circuit must be equal to the value of $LC$ for the other circuit. Fuller details of tuning to resonance in wireless circuits are, however, given in subsequent chapters.

In the above example of resonance the capacity and inductance were in series and such a case is often referred to as *series resonance.* Another peculiar result occurs if a capacity and inductance be in parallel in an alternating current circuit and the condition for resonance be practically satisfied. If an example of this type be worked out, it will be found that although *the currents in the two branch circuits may be quite definite and even large, the current in the main circuit and through the alternator will be quite small*—theoretically, with zero resistance, the current in the main circuit would be zero : such a case is often referred to as *parallel resonance.* As the student will see later, the principles of series and parallel resonance are made use of in wave traps (acceptor and rejector circuits) employed in wireless receiving circuits.

So far we have defined a high frequency oscillatory current simply as an alternating current whose frequency is about 100,000 cycles per second or more : in wireless, where resonance plays such an important role, it is customary to say that an oscillatory current is an alternating current flowing in a circuit whose resistance is very small, the frequency being $1/6\sqrt{LC}$ where $L$ is the inductance in henries and $C$ is the capacity in farads.

The preceding is only a very elementary treatment which omits many factors, so that the formulae and the results only approximate to what occurs in practice. It is, however, intended merely to give the beginner a general idea of what is always at first a somewhat difficult problem ; he can fill in details when his studies have taken him into the higher stages of the subject.

It may be noted in passing that the resistance of a solid conductor to high frequency currents is very much greater than its resistance to steady or continuous currents. This is partly due to the fact that the oscillations have not time to soak or sink into the metal, so that only the skin or surface contributes to the conduction. It is also partly due to the fact that the oscillations—rising, falling, and reversing currents—set up eddy currents in the conductor. Thin wires, which may be looked upon as practically all surface, are more efficient than thick ones, weight for weight. Stranded insulated wires, comparatively thin, are largely used for high frequency currents owing to the larger proportion of surface area available.

# CHAPTER VII.

## THE PRODUCTION, PROPAGATION, AND DETECTION OF "WIRELESS" WAVES.

89. **Introduction.**—It is a well known fact that if the prongs of a tuning fork be put in vibration, *i.e.* given a regular to and fro movement, a **sound wave**, as it is called, is set up in the air which can be detected by the ear. The air in the vicinity of the vibrating body executes a slight to and fro movement in unison with it: this movement is communicated to the air in front and so on, until finally the vibratory motion reaches the air in contact with the drum of the ear, with the result that the latter responds and the sound is heard.

The action may be explained in a little more detail. Imagine the prongs of the tuning fork to be pressed towards each other, between the finger and thumb. They are now "charged" with a quantity of energy stored up as potential energy of strain in the material of the prongs. When the prongs are let go this energy is "discharged" by a rapid series of swings, in each of which there is a change from the potential energy of strain into kinetic energy of motion, and a change back again from this kinetic energy into strain potential energy. During each swing, also, there is a loss of energy as heat due to molecular friction in the prongs, and during the vibration of the fork energy is radiated out into the air as sound waves. The student should particularly note that these sound waves are *waves in the air*; if the air between the vibrating body and the ear were removed no waves would be propagated and no sound would be heard.

An *oscillation* (as will be known from previous chapters) is a single swing of the vibrating fork from one extreme position to the other. A *vibration* is a double swing—a "to and fro" movement. The **wave length** is the distance the wave travels during one complete vibration. The **frequency** is the number of complete vibrations in one second. Hence the **velocity** of the sound wave, *i.e.* the distance it travels in one second, is evidently given by the expression :—

Velocity = Wave Length × Frequency.

Now the velocity of sound waves in air is comparatively constant and equal to about 1,120 feet per second ; hence it follows that *the faster the fork vibrates, i.e. the higher the frequency, the shorter will be the wave length, and conversely, the lower the frequency the longer will be the wave length*, for in each case the product of the two is 1,120. The **periodic time** is the time taken for one complete vibration.

Further, if we uncover the strings of a piano and sound a tuning fork near them it will be noted that several of the strings will be affected by the waves from the fork, but that particular string which has the same vibration frequency as the fork will be affected most, and it may be set so strongly in vibration that it gives out the same note as the fork. Similarly, when a piano is being played it sometimes happens that a vase in the vicinity is set strongly in vibration when a particular note is struck, due to the fact that its dimensions, etc. are such that it has a natural frequency of its own equal to that of the note which affects it. These are further examples of what is called **resonance** : the two vibrating bodies are said to be *in tune* or *in unison* or *in resonance* with each other. Several other cases of resonance in connection with vibrations in general will probably occur to the reader. It will be evident that the *general principle* is the same as that of resonance in the alternating current circuits dealt with in Art. 88.

Water is another well known medium in which a wave motion can be set up. Long waves in water are caused by wind and the gravitational pull of the earth. Imagine, however, that a stick is moved gently up and down at the centre of a large pond. In this case genuine water waves will be set up, *i.e.* the particles of water will move up and down forming in succession " crests " and " troughs," and a wave motion will spread outwards in all directions.

Consider the water heaped up in a crest as shown in Fig. 82. Now there is an attraction, known as *surface tension*, between the molecules on the surface of water, and in Fig. 82 this force of surface tension (marked $T$) tends to flatten out the water again, and it moves downwards to the normal position $XY$. In moving downwards, however, another force is called into play known as the *force of inertia* (marked $I$) and this carries the water below $XY$ so that the crest changes into a trough. The force of inertia now ceases, but the surface is once more stretched and the force of surface tension comes on again, thus raising up the trough, and the action is repeated. These movements are communicated to the water beyond, and the wave motion spreads outwards.

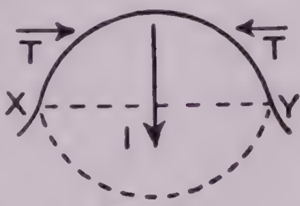


Fig. 82.

It will be noted that the up and down movement of the water—the vibration—is due to two forces, $T$ and $I$, acting at right angles to each other. Further, that the wave conveys energy can be shown by placing a stick on the surface: when the waves reach the stick the latter bobs up and down, the former movement indicating that work is being done against gravity, and that therefore the wave is endowed with energy. The importance of all this lies in the fact that in "wireless" we have in the same space two forces at right angles—an electric field and a magnetic field—and that we have a wave motion, and therefore a movement of energy, out into the surrounding medium, which in this case is the **aether**.

**90. Oscillatory Discharge of a Condenser.**—When the plates of a charged condenser are connected by a large resistance the discharge consists of a steady flow from one plate to the other, the charges thus neutralising and the potentials of the plates both becoming zero. If, however, the resistance be below a certain value, the discharge consists, not of a steady flow, but of a number of rapid oscillations or surgings of electricity to and fro: the first "rush" more than neutralises the opposite charge and charges the condenser in the opposite direction; this is followed by a reverse rush which again "overshoots the mark" and charges the condenser in the same way as it was originally, and so on (Arts. 70, 77). Each successive oscillation is weaker than the preceding; thus, after a number of such surgings the discharge is complete and the potentials of the plates equalised. Such a surging of electricity to and fro may be graphically represented by the curve shown in Fig. 83.

At each oscillation the electrostatic energy of the condenser field is converted into electromagnetic energy due to the current flowing, and then back again into electrostatic energy, the changes being accompanied by the dissipation of energy as heat in the conductor and also by electric radiation as explained below. These oscillations take place very rapidly, and although they get weaker the time of each is the same.

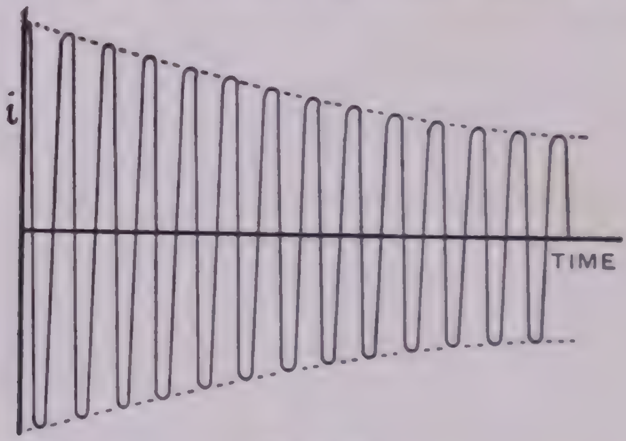


Fig. 83.

As the result of these transformations of energy it is evident that the portion of the medium (the aether) involved primarily in the transformations *must undergo a definite periodic variation of state.* This variation of state is propagated with finite velocity throughout the aether, that is, we have **a set of electric or electromagnetic waves** *which travel outward in all directions into the medium with a definite finite velocity.* This velocity has been proved, theoretically and practically, to be 186,000 miles per second, or 300,000,000 metres per second, the same as that of light.

Oscillations such as those depicted in Fig. 83, which gradually weaken or decrease in amplitude and finally die out, are spoken of as **damped oscillations**, and the resulting waves are known as **damped waves**.

Now it can be shown that the frequency and wave length of these waves depend on the three important properties of the electrical circuit, viz. **resistance, inductance**. and **capacity**. If we neglect the resistance on the assumption that it is kept small, it can be shown that :—

$$\text{Frequency is proportional to } \frac{1}{\sqrt{LC}}$$

$$\text{Wave length is proportional to } \sqrt{LC}.$$

where $L$ is the inductance and $C$ is the capacity of the electric circuit : this approximate expression is sufficient for the student at this stage. He should note that increasing the inductance or increasing the capacity of the circuit decreases the frequency and increases the wave length : he should also note that the damping or weakening of the oscillations (Fig. 83) when we have an oscillatory electric discharge in the circuit in question is partly due to resistance in the circuit, and partly due to energy being radiated out into the surrounding medium. The first expression above is, of course, when more fully stated, our friend $f$ of Art. 88.

We can also consider the above in a little more detail, modifying the arrangement, as shown in Fig. 84, so as to obtain an important circuit which is actually used in wireless. This is referred to as an **oscillatory circuit**, $C$ being the capacity, and $L$ the inductance necessary for an oscillatory current. $S$ is a gap across which sparks can pass when the condenser discharges, and $A$ and $B$ are wires leading to the arrangement used for charging the condenser.

(*a*) Imagine the condenser is fully charged and just on the point of discharging across the spark gap (Fig. 84 (*a*)). At this stage we have an electrostatic field and electric lines of force as indicated, and we say that the aether is in a state of **electric strain**. (Arts. 21, 33),

(*b*) Imagine now that the spark passes as shown in Fig. 84 (*b*). This means that electrons are passing round the circuit—in other words that a current is flowing—thus tending to equalise the potentials. The electric strain disappears, but we have now a magnetic field and magnetic lines of force round the current circuit as shown, *i.e.* the aether is now subject to what we term a **magnetic strain**. (Arts. 32, 33).

(*c*) Owing to the inductance or inertia, the discharge current flows on—overshoots the mark—so that the circuit becomes as in Fig. 84 (*c*). We have again a difference of potential, but in the opposite direction, *i.e.* the condenser is charged the other way about. Once more we have an electrostatic field and electric lines, and the aether is again subject to electric strain.

(*d*) The discharge now takes place in the opposite direction (Fig. 84 (*d*)) giving changes similar to those indicated in (*b*).

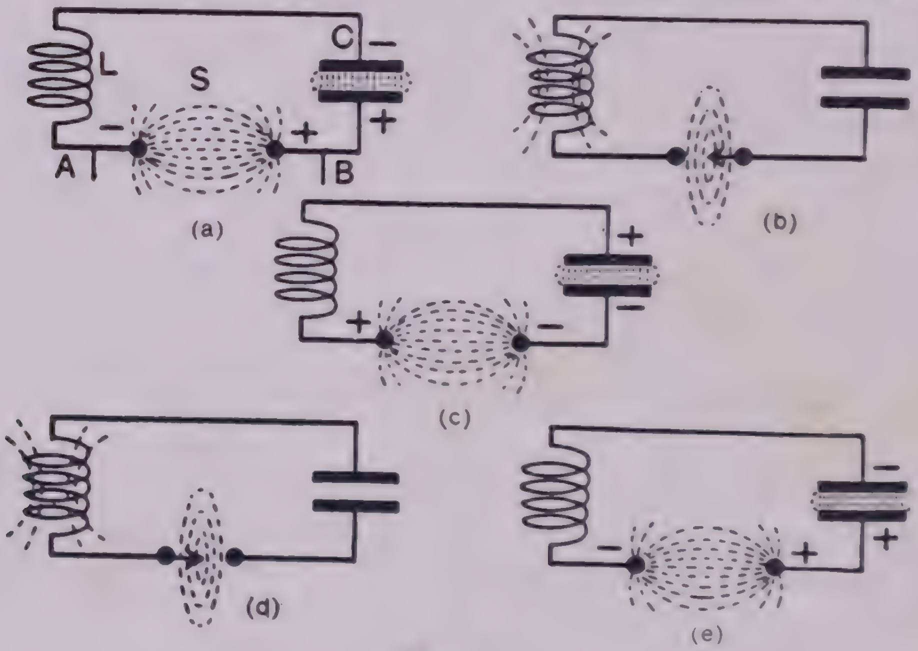


Fig. 84.

(*e*) Once more, owing to inductance or inertia, the discharge current in (*d*) overshoots the mark, charging the condenser the other way about (Fig. 84 (*e*)) and giving changes similar to those indicated in (*c*). We are now back to the original condition in the sense that the upper plate of the condenser is negatively charged, and the lower plate positively charged.

These actions are repeated, but, of course, at each swing a certain amount of energy is lost, so that the oscillations gradually get less and finally die out. The time taken for the circuit to pass through the double swing from the state shown in Fig. 84 (*a*) to the state shown in Fig. 84 (*e*) is the periodic time, and the number of such time intervals or double swings in one second is the frequency.

It will be noted that in the above oscillatory circuit we have two rising and falling strains—magnetic and electric—at right angles to each other, and that a portion of the energy is transmitted out through the surrounding medium—the aether—by a wave motion, the direction of propagation being, in fact, at right angles to both the magnetic and electric forces.

There is, however, one further point which should be mentioned in connection with the preceding. In Fig. 84 (*a*) we have an electric field and electric lines but no current and no magnetic lines; in Fig. 84 (*b*) we have a current and magnetic lines but no electric lines, and so on. Thus at the oscillator the electric disturbance and the magnetic disturbance are not in step with each other: one is a quarter of a period behind the other, just like the piston and slide valve of an engine. Now the progression of the wave through space demands that both forms of energy—electric and magnetic—should exist together and be in step, *i.e.* when one is a maximum the other must be a maximum (or nearly so), and when one is a minimum the other must be a minimum, and it can be shown that this state of affairs does exist at a distance of one quarter of a wave length from the oscillator. Within this distance the energy simply pulsates in and out, but at this distance the magnetic and electric disturbances have got in step and wireless waves pass onwards through the aether with the velocity of light.

A **closed oscillatory circuit** such as that shown in Fig. 84 does not, however, lead to much energy being radiated out in the form of waves, but if the circuit be, as it were, opened out (as was done by Hertz), or if it be made to act inductively on what is called an **open oscillatory circuit**, energy is readily transmitted by a wave motion through the aether; such circuits will be dealt with in the sections which follow.

**91. Early Experiments in Wireless.**—Early work on wireless waves was done by Henry in 1838, Kelvin in 1853, and Clark Maxwell in 1863. In 1888, however, Hertz published an account of his experiments on the production, propagation, and detection of the waves, and these are often spoken of as the starting point of practical wireless. The experimental work of Lodge, Fleming, and others in these early days must, however, not be forgotten.

Hertz's **oscillator** or **transmitter** consisted of two metal plates connected to the spark gap of the secondary of an induction coil (Fig. 85), the capacity between the two plates and the inductance of the connections between them forming the necessary capacity and inductance for the oscillatory circuit. It will thus be seen that Hertz really opened out the condenser plates of Fig. 84, thus facilitating the transfer of energy in the form of waves throughout the aether medium: his oscillator was the first open type of oscillator.

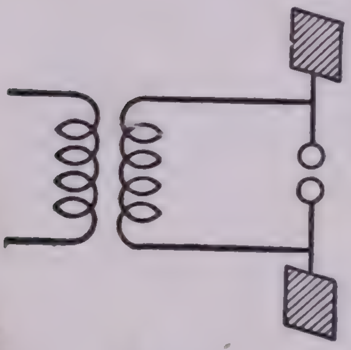


Fig. 85.

The action is identical with that explained in the preceding article. When the induction coil is worked, the upper plate, say, is charged to a higher potential than the lower plate, then a spark passes, and the path of this spark, on account of its comparatively low resistance, practically connects the plates as one conductor, and the potential is equalised by very rapid oscillations of electricity in this conductor. The cycle of changes that goes on in the medium near the vibrator during one oscillation is that associated with the transformation of electrostatic to electromagnetic energy, the re-transformation of electromagnetic to electrostatic energy, and so on, and, during these, a gradual dissipation of energy as heat in the circuit and a further loss due to radiation. In short the cycle of changes is transmitted out into the medium, and the sequence of states so transmitted constitutes the electric or electromagnetic or "wireless" waves.

When the waves from this oscillator pass a conductor they tend to reproduce the electrical conditions in it, that is electrical oscillations are induced in the conductor, and small sparks may be caused between conductors placed close together.

Hertz took advantge of this to detect the waves. One form of **detector** used by him was a piece of thick copper wire bent into a circle (Fig. 86), but with a small air-gap between the ends of the wire; the width of the gap could be adjusted. As the waves passed through this circuit small sparks were observed at the gap, and it was found that the sparks were strongest when the dimensions of the detector were such that its period of oscillation as an oscillator was the same as that of the oscillator originating the waves. This is again an example of the general principle of *resonance* already referred to, and a circuit showing electric resonance is specially effective in detecting electric waves. By the proper adjustment of inductance and capacity it is possible to adjust the period of the detector within fairly wide limits, and so *tune* it to resonance in any particular case.

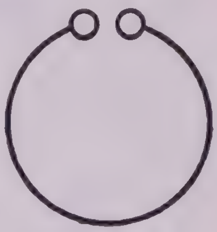


Fig. 86.

About 1895 Marconi discovered that if one of the spark gap terminals of the induction coil used in Hertz's transmitter were connected to a plate buried in the ground, the surface of the earth could be used as one plate of the condenser; and also that the higher the other plate was above the ground the greater was the distance over which he could transmit electromagnetic waves. He found that an actual upper plate was unnecessary, and that a vertical wire (the **aerial**) supported by a kite or masts gave similar results, the capacity in this case being distributed along the wire. It was found better, however, to use a number of wires in parallel for the upper portion of the aerial in order to increase the capacity for transmission on longer wave lengths. Fig. 87 shows the principle of Marconi's transmitting arrangement, the variable inductance in the aerial circuit enabling the circuit to be tuned to various wave lengths. The induction coil is shown on the left.

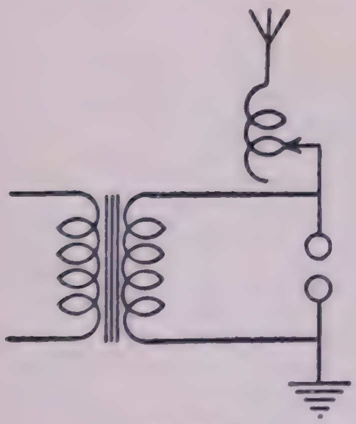


Fig. 87.

At the receiving station the waves from the transmitting station encountered a similar aerial and set up electrical oscillations in it of the same frequency as those at the transmitting station, the receiving aerial being tuned to the arriving waves by variable inductances and capacities. This receiving aerial was electrically connected to a detecting device to indicate the presence of the incoming waves.

Previous to this, the **coherer** as a detecting device for electromagnetic waves had been investigated by Lodge and Branley, and this was the type of detector used by Marconi in his early experiments. A simple form of coherer is shown in Fig. 88. Two brass, copper, or silver discs *d*, *d*, each soldered to the end of a copper wire *w*, are fitted into the glass tube *gg*, and a thin layer of filings rests lightly between the discs. If this coherer is placed in the circuit of a battery and an electric bell, the contacts made by the filings between the discs may be so adjusted that the current passing will not be strong enough to ring the bell. If, however, waves from a distant oscillator fall upon the coherer after this adjustment is made, the contact at once becomes good and the bell in the circuit rings. If the coherer is slightly tapped the contact fails and the arrangement is again ready to detect the incidence of the waves. In Marconi's coherer the plugs *d*, *d* were of silver, the filings a mixture of nickel and silver, and the tube was exhausted and sealed.

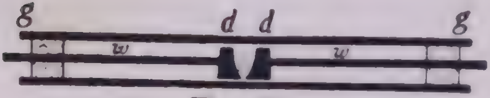


Fig. 88.

Fig. 89 shows Marconi's first transmitting circuit in greater detail. The spark gap consists of two small spheres sparking across the diameters of two larger ones. The key in the primary circuit enables the train of sparks to be continued for a long or a short period of time, thus producing the "longs" and "shorts," *i.e.* the "dashes" and "dots" of the Morse Code (see below), and enabling intelligible messages to be transmitted. It will be seen that the circuit follows closely the experiment of Hertz.

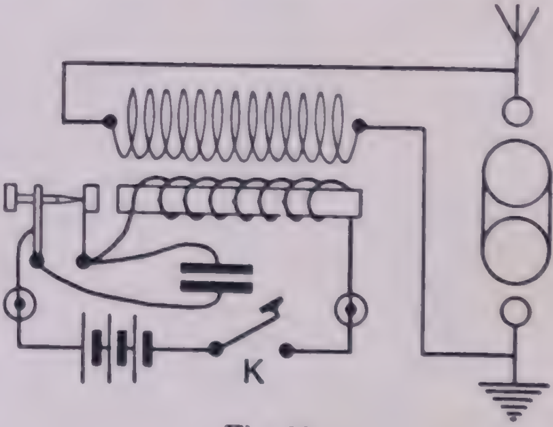


Fig. 89.

Marconi's first receiving circuit is depicted in Fig. 90. The waves arriving at the aerial result in the filings of the detector $C$ "cohering," and current from the battery $B$ flows in the direction $BRYCXB$. This current magnetises the electromagnet $R$, so that the armature $A$ is attracted, making contact with the stud $S$. The circuit of the battery $B_1$ is now closed, with the result that current flows from it through the telegraph instrument $T$ and the signal is recorded. At the same time a current passes from $B_1$ through the coils of the electric bell $F$, the hammer of which taps $C$ and decoheres the filings, so that $C$ is again ready to respond to incoming waves.

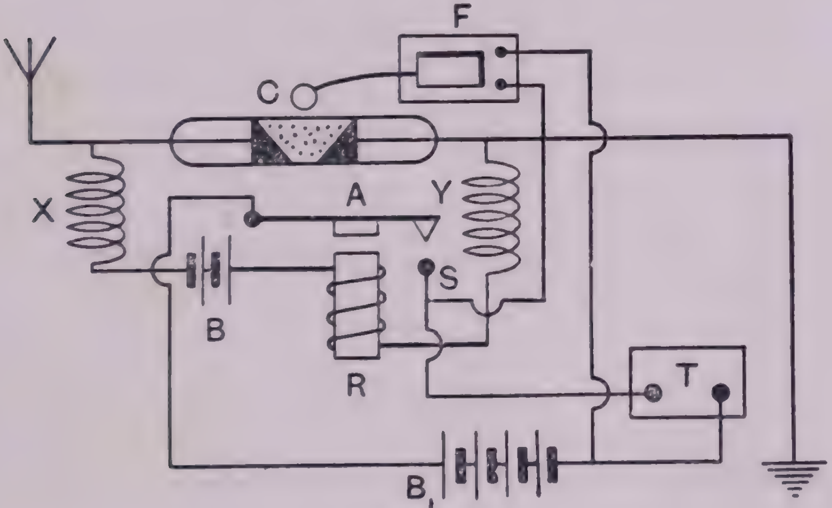


Fig. 90.

It must be understood that it is necessary for the transmitting circuit to be tuned to the required wave length to be transmitted, and for the receiving circuit to be likewise tuned to the wave length to be received.

After the coherer came other detectors known as **magnetic detectors** and **electrolytic detectors**, but later these were replaced by the **crystal detector** and the **valve detector**, and they need not be discussed here. Crystal and valve detectors are dealt with later.

It is important for the beginner to visualise how the operator at the transmitter controls the wireless waves (by key $K$ in Fig. 89) so as to send messages to the operator at the receiver.

By means of the key the currents can be made to flow up and down the aerial for long or for short periods of time. For a long signal the key is kept down three times as long as for a short signal. Combinations of longs and shorts—dashes and dots—form letters according to the code known as the Morse Code, *e.g.* A · —, B — · · ·, C — · — ·, etc.

Now in the spark system which we have been considering, high frequency currents, *i.e.* oscillating currents, are being produced while the spark is passing : they gradually die down and then when another spark passes they flow again and gradually die down, and so on. Hence there are times when wireless waves are being sent out by the aerial and times when no wireless waves are being sent out, although the key may be depressed all the time. Fig. 91 will make this clear.

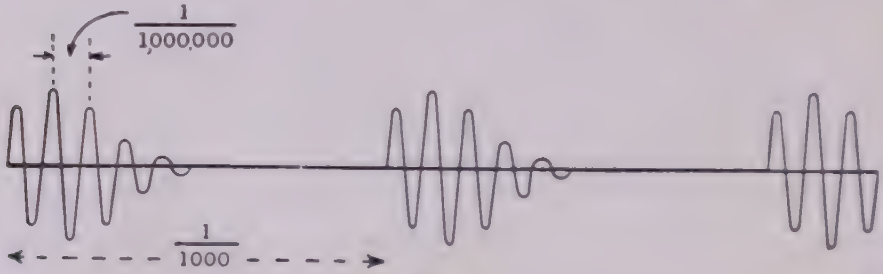


Fig. 91.

The number of times the spark occurs in one second is called the **spark frequency** or **note frequency,** whilst the number of complete vibrations of the high frequency current in one second is often referred to as the **wireless frequency** ; this latter is the frequency mentioned in the preceding pages.

The time between the successive crests of the high frequency or oscillatory current is very short, of the order $\frac{1}{1000000}$ of a second (Fig. 91). On the other hand the time between the sparks is longer, of the order $\frac{1}{1000}$ second. The time the operator keeps the key down in order to send a short signal or dot is much longer still, viz. $\frac{1}{5}$ second. It is thus clear that even during the sending of a dot there is a succession of many sparks producing the signal, so that the fact that the trains of oscillations are intermittent causes no inconvenience in the sending of the dot and dash signals.

**92. Improvements in Transmitting Circuits and Receiving Circuits.**—In a book intended for beginners it is impossible to explain fully the various improvements which have taken place since the earlier methods of wireless transmission and reception dealt with in the preceding article were in operation: a few essential steps only in the rapid development can be indicated.

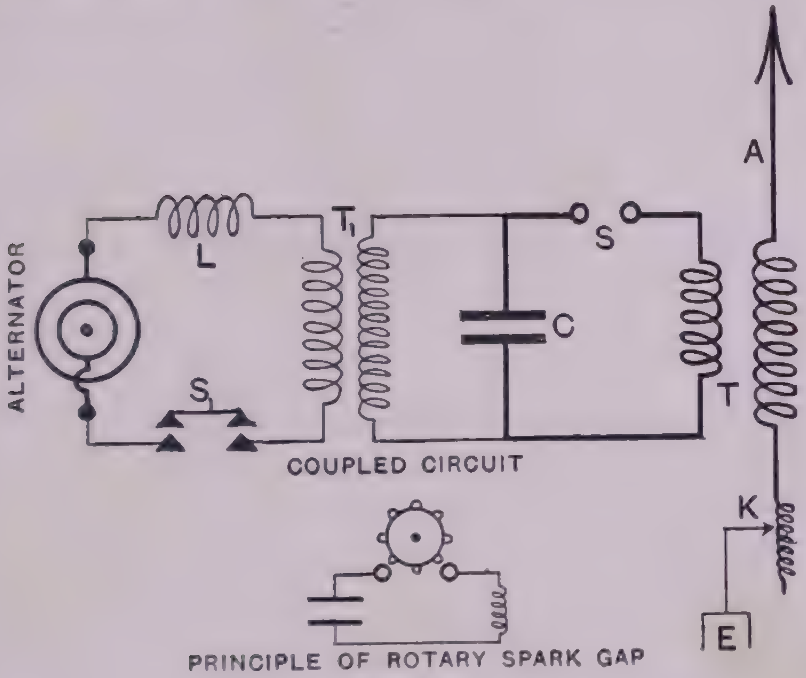


Fig. 92.

An improvement was made in the transmitting circuit by **coupling** the aerial circuit to a closed oscillating circuit as shown diagramatically in Fig. 92. The condenser $C$ and spark gap $S$ are in series with the primary winding of a transformer $T$, the secondary of the transformer being joined to the aerial $A$ and to earth through an inductance. The contact $K$, and therefore the inductance in series with the aerial, is adjusted until the aerial circuit and condenser circuit are syntonised, *i.e.* until the period of oscillation of the aerial circuit is equal to that of the condenser circuit. The "charging" is effected from the secondary of the transformer $T_1$, the primary of which is connected to an alternator; this circuit also includes an inductance $L$ and a switch $S_1$, the latter being used to produce the required "longs" and "shorts" of the Morse code. At each discharge oscillations occur in the condenser circuit; these induce oscillating electromotive forces and currents in the aerial circuit, and the two being syntonised the aerial becomes a powerful source of radiation of waves.

In place of the simple spark gap $S$ a **rotary spark gap** is often employed. A wheel carrying a number of projecting studs is rotated between fixed studs in the condenser circuit, and arrangements are such that the fixed and moving studs come opposite each other at the instant when the condenser is fully charged, *i.e.* just when the spark is required.

At the present day, most wireless stations working with spark gaps and damped oscillations and transmitting damped waves use, in some form or other, the alternator and step up transformer method indicated in principle in Fig. 92.

In the method in question we have seen that energy is conveyed to the aerial coil by induction from the primary or condenser circuit, and therefore it would seem advisable to couple the two circuits as **tightly** as possible, by, for instance, winding the aerial coil of the transformer $T$ over the primary coil of $T$ so that all the magnetic lines of the primary coil will act on all the turns of wire in the aerial coil. Such tight coupling would, however, not be efficient for our purpose. What we want in wireless is really a large number of oscillations and considerable energy in the aerial. If, however, the coupling is tight, the aerial circuit strongly reacts (inductively) on the closed circuit, that is, energy is transferred from the aerial circuit back to the closed circuit, and the aerial oscillations are *on the whole* damped down. Moreover, tight coupling in the present case can be shown to result in the radiation of two waves of different frequencies. All this indicates that the coils should be **loosely** coupled, not tightly coupled, to secure good results. In practice, therefore, we must aim at the best compromise.

In what is called the **quenched spark gap system**, the electric discharge across the spark gap oscillates only a few times before it is quenched or extinguished and *the gap made non-conducting*; this is done just at the instant that the maximum energy is transferred to the aerial circuit for the first time. The aerial circuit in this case cannot transfer energy back to the closed circuit to the extent it does in the preceding case, for the gap is non-conducting and current cannot flow. Thus the damping in the aerial circuit is very slight, so that its oscillations continue, and there is a large number in each train of waves; hence tight coupling can be utilised in such a case. Fig. 93 shows the oscillations in the primary or closed circuit and in the secondary or aerial circuit when the coupling is tight, and Fig. 94 shows the oscillations when the spark is quenched after $2\frac{1}{2}$ oscillations. The figures clearly indicate the general principles referred to above.

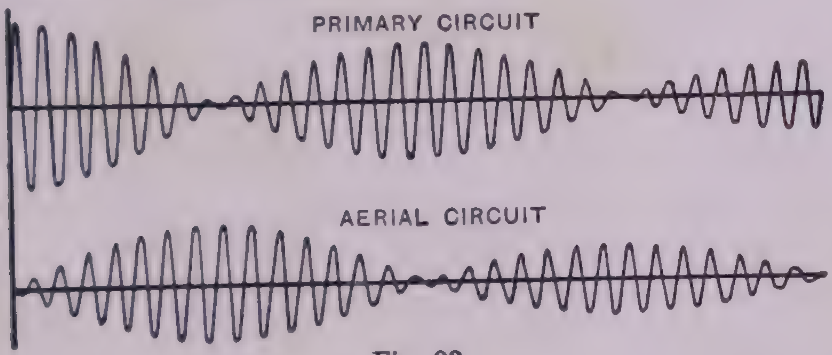


Fig. 93.

Further developments in transmitting circuits lie mainly in the direction of the substitution of undamped oscillations and undamped waves for the preceding damped oscillations and damped waves; these are referred to in Art. 93.

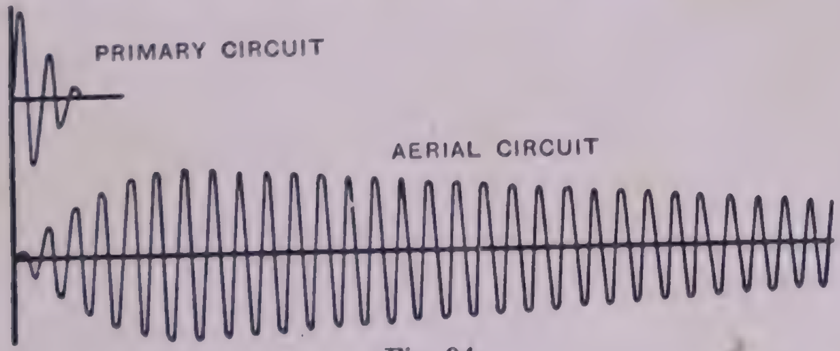


Fig. 94.

We have seen that at the receiving station the waves from the transmitting station encounter a similar aerial and set up electrical oscillations in it of the same frequency as those at the transmitting station, the receiving aerial being tuned to the arriving waves by variable inductances and capacities. Fig. 95 shows three methods usually employed in tuning the receiving aerial to the arriving waves (the dotted lines merely represent the capacity of the aerial to earth). In (*a*) tuning is done by a variable inductance, in (*b*) by a variable condenser in parallel with the inductance (which may itself be fixed or variable) whilst in (*c*) the variable condenser is in series with the inductance (which may again be either fixed or variable). It will be remembered that since the wave length to which the aerial is tuned depends on the inductance and capacity, being in fact proportional to $\sqrt{LC}$, increasing either the aerial inductance or capacity will tune the receiving aerial to a longer wave. It should also be noted that a series condenser, *i.e.* one in series with the inductance gives a lower wave length than a parallel condenser, *i.e.* one in parallel with the inductance. Further details as to the tuning of receiving circuits are given in subsequent chapters.

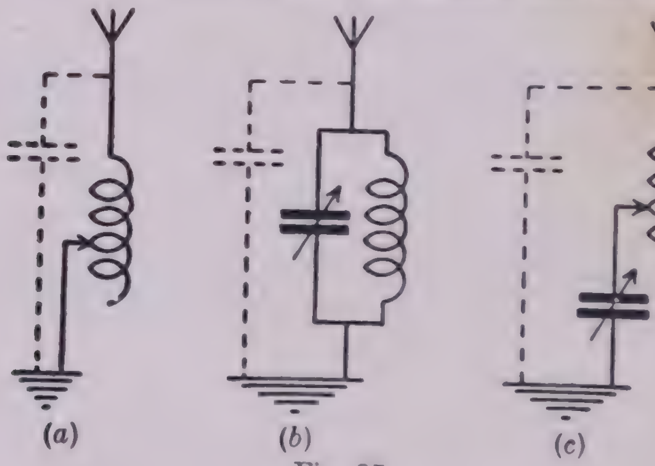

(*a*) (*b*) (*c*)

Fig. 95.

As already indicated, in addition to the tuned receiving aerial, some device, *e.g.* a telephone or sounder, must be electrically connected to the circuit so as to render the signals which are arriving perceptible to the operator. Now the oscillating currents set up in the aerial are of too high a frequency to operate these devices directly. To enable these to respond some means must be adopted for producing, in the detecting part of the receiving circuit, *unidirectional or low* *frequency currents* which must of course vary according to the trains of waves arriving at the aerial; this is the fundamental requirement of what is usually called a **detector**—or more exactly a **rectifier**—of which the crystal and the valve are the two types now mainly employed. It will be remembered that the coherer, when used as a detector, really caused a *unidirectional* current from a battery to operate the telegraph instrument.

The action of a crystal depends on the fact that current can only pass through it in a certain direction, so that it changes an oscillatory current into a unidirectional current by stopping the flow in one direction. Fig. 96 shows a method of using a crystal as a detector or rectifier, a telephone being used as a receiver. The varying potential differences on the inductance due to the arriving waves tend to set up oscillatory currents in the crystal circuit, but the crystal refuses the current in one direction, so that a unidirectional current flows each time a group of oscillations is set up in the aerial, *i.e.* each time a spark passes at the transmitter. The note heard in the telephone is therefore of the same frequency as that of the sparks at the transmitter, and it starts and stops when the train of sparks starts and stops.

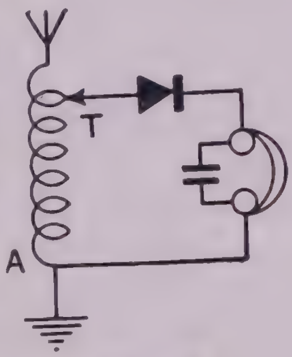


Fig. 96.

The actual construction of the crystal detector or rectifier in Fig. 96 is explained in Chapter VIII. The condenser across the telephones is for the purpose of providing a "by-pass" for any high frequency oscillations in this part of the circuit, which, in its absence, would pass through the telephones.

This rectifying action of the crystal and the resulting effect on the telephones will be better understood by considering Fig. 97 which shows the application of the crystal to the incoming oscillations. The crystal may be regarded as wiping out all the alternations or half puffs say below the centre line and allowing only the half puffs above the line to pass. These half puffs or rectified currents which, although varying in strength, flow only in one direction, pass through the telephones.

Since the telephones are unable to respond to the separate high frequency oscillations (which only occupy say $\frac{1}{1000000}$ second) of Fig. 97(*a*), they will still be unable to respond to the separate puffs of the rectified current of Fig. 97(*b*), but these separate puffs may be looked upon as collected together to form a slowly varying unidirectional current as indicated in the lower part of Fig. 97, and to this the telephones respond. Using the numerical value given in Fig. 91, we have a rush of current through the telephones every $\frac{1}{1000}$ second, which tends to attract the diaphragm as it rises and to allow the diaphragm to go back as it falls. The telephones can easily respond to this frequency, so that they send out sound waves at a frequency which is well within the range of the human ear. Thus the sound actually heard in the telephones has a frequency equal to the spark frequency of the transmitter.

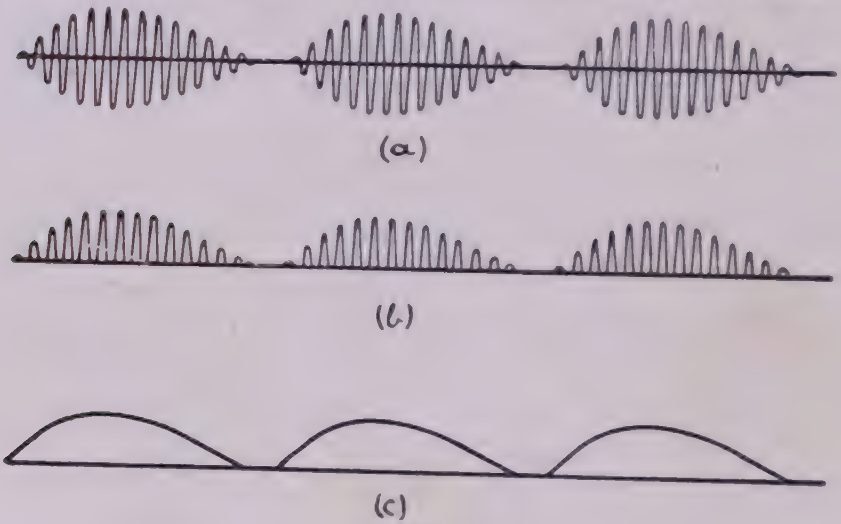


Fig. 97.

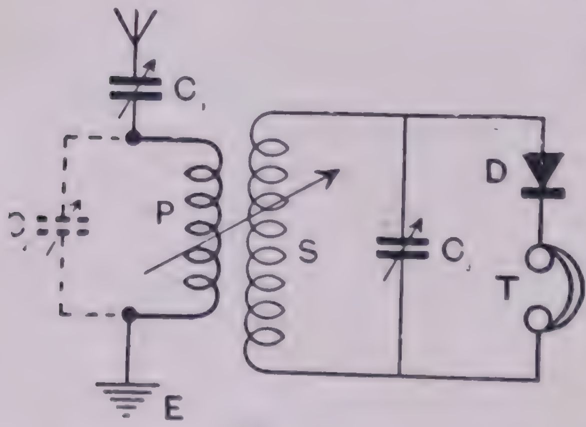


Fig. 98.

Another arrangement using a coupled circuit is shown in Fig. 98. The aerial circuit is tuned to the arriving waves, and the $SC_3$ circuit is tuned to the aerial circuit. A full explanation of crystal receiving circuits is, however, given in succeeding chapters.

Following the crystal as a detecting device comes the thermionic valve; this also is explained in succeeding chapters.

**93. Undamped Oscillations and Undamped Waves.**—Transmitting sets producing **undamped oscillatory currents** which give rise to **undamped** or **continuous waves** are now largely used and particularly for purposes of wireless telephony: indeed, although spark methods and damped waves were originally used in transmitting speech, it is the advent of the undamped wave which has made wireless telephony the success it is to-day. Corresponding to Fig. 83 for damped oscillations, the lower part of Fig. 99 depicts oscillations which are undamped.

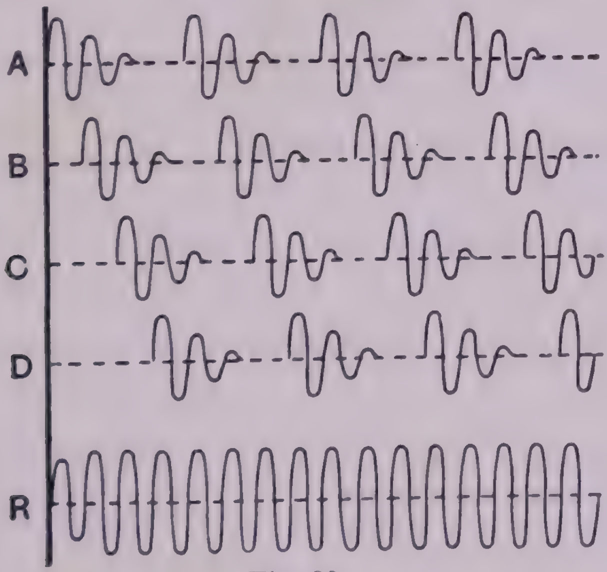


Fig. 99.

A method of producing undamped oscillations and waves, due to Marconi, is indicated in principle in Fig. 99. Imagine four different circuits *A*, *B*, *C*, *D*, in which damped oscillations are produced similar to those already dealt with, and imagine, further, that arrangements are such that the discharges follow each other in a regular order as shown. If now these oscillations are made to act inductively on a fifth circuit—an aerial circuit—the resulting oscillations will be as shown at *R*, *i.e.* the resultant oscillations will be undamped or continuous, giving rise to undamped waves.

Another method, largely due to Poulsen, makes use of a carbon arc lamp, and the principle of the method will be gathered from Fig. 100, in which the carbon arc practically replaces the spark gap in the closed oscillatory circuits previously dealt with. Imagine the arc formed and the condenser fully charged so that an oscillatory current starts up in the closed circuit. During one half cycle the oscillatory current will be flowing through the arc in the same direction as the current through the arc from the battery, while during the next half-cycle the oscillatory current will be in the opposite direction to the main arc current.

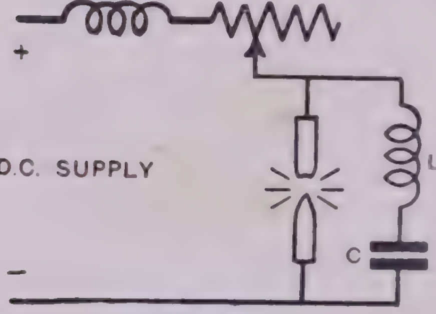


Fig. 100.

Now the resistance and potential difference across an arc decrease when the current increases, and increase when the current decreases. Hence when the oscillatory current goes through in the same direction as the main arc current, the resistance is lessened, the damping is reduced, and therefore the oscillations tend to continue. When the oscillatory current goes the other way, the potential difference on the arc increases and charges up the condenser until the potential difference across the arc is normal again, at which stage the condenser discharges, and the oscillatory current is maintained at constant amplitude.

It is evident, therefore, that the oscillatory currents produced by an arc are undamped or continuous oscillations, and any waves thrown out will be undamped or continuous waves.

Fig. 101 shows one arrangement of the arc at a transmitting station for the production of these undamped or continuous waves (C.W.). The arc is in series with the aerial, and a condenser is joined between it and the earth to stop the direct or continuous current from going to earth. In the preceding spark systems the transmitting key started and stopped the sparks in order to produce the signals. This is inconvenient here for, at a stop, the arc would be extinguished and would have to be re-struck--a bothering business. Hence the key is put across part of the inductance as shown so that it alters the wave-length being transmitted. When the key is closed the wave going out is the signal: when it is opened the new wave going out denotes the "space" between signals. Our telegraphist readers will recognise that the first is the "marking wave" and the second the "spacing wave." Other arrangements are, of course, employed.

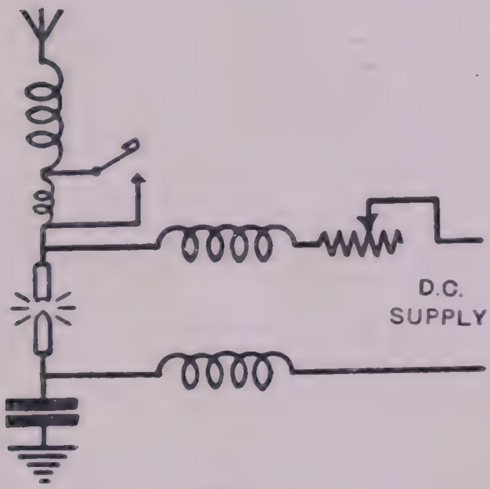


Fig. 101.

There are other methods of producing continuous waves, *e.g.*, by high frequency alternators, or alternators in conjunction with transformers which raise the frequency (page 126), but most successful of all are methods using thermionic valves. Such valve methods will be understood after valve circuits have been dealt with.

At the receiving end the continuous or undamped oscillatory currents can be rectified as already indicated for damped oscillatory currents, but as far as the telephone is concerned, it will be apparent that the diaphragm will be attracted as soon as the waves arrive and will remain attracted until the waves cease, owing to the continuous nature of the rectified puffs. The receiving operator will thus hear one click when the signal begins and another click when the signal ends, and the messages will be very difficult, if not impossible, to read. Clearly then, something must be done either at the transmitting end or at the receiving end to break the waves up into short trains of waves, and to do this at such a rate (frequency) that a note is produced in the telephone.

A method originally used was to insert a rotating arrangement in the detecting circuit whereby this circuit was broken for short intervals of time, but this method has been replaced by the **heterodyne method** due to Fessenden. In this method the incoming oscillations are combined with other oscillations of a slightly different frequency, and the two combined produce a resultant current which increases and decreases in strength at a rate depending on the difference in the frequencies of the two oscillations. Fig. 102 will make the principle clear. Here *A* depicts the incoming high frequency oscillations, *B* the oscillations of a slightly different frequency, locally produced, and *C* shows the resultant of the two. The telephone responds to *D*, the actual note heard depending on the frequency of these resultant puffs. The effect resembles very closely the phenomenon of beats in music.

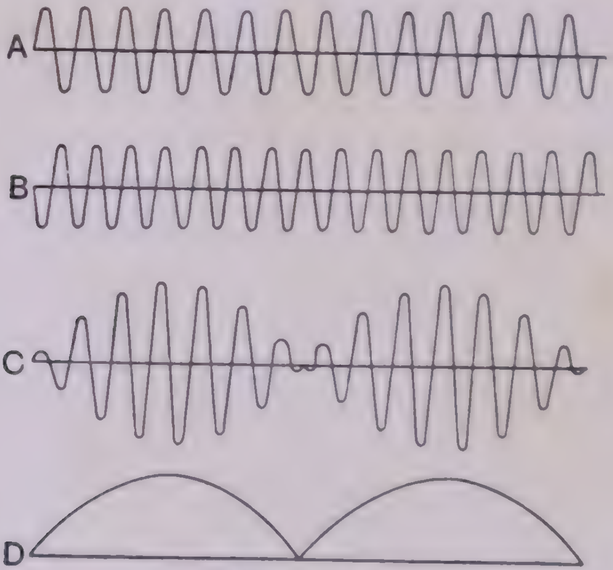


Fig. 102.

The production of these local oscillations which have to be combined with the continuous oscillations will be understood when valve circuits and reaction have been studied in Chap. XI.

The broad principle of wireless telephony—the transmission of speech, music, etc. as distinct from Morse transmission in telegraphy—may now be briefly indicated. The undamped high frequency electrical oscillations in the transmitting aerial produce an undamped wave which is passing out all the time wireless telephony is being transmitted. This wave is called

**the carrier wave.** In series with the transmitting aerial is a microphone so that the oscillating aerial current passes through it. When the "broadcaster" speaks into the microphone, the variations which he produces in the microphone resistance cause corresponding variations in the oscillating current in the aerial, so that we have a resulting current in the aerial which varies up and down in a most complicated way according to the words spoken. This again in turn produces a complicated aether wave varying according to the words spoken, which when it reaches the receiving aerial sets up corresponding electrical oscillations in it which are "detected," and the sound reproduced in the usual way. The essential fact is that the speech of the operator is caused to **modulate** the carrier wave, and the receiving telephone reproduces the sound to which the modulated wave is due. Fig. 103 (*a*) depicts a carrier wave and Fig. 103 (*b*) a modulated wave when the operator is speaking into the microphone.

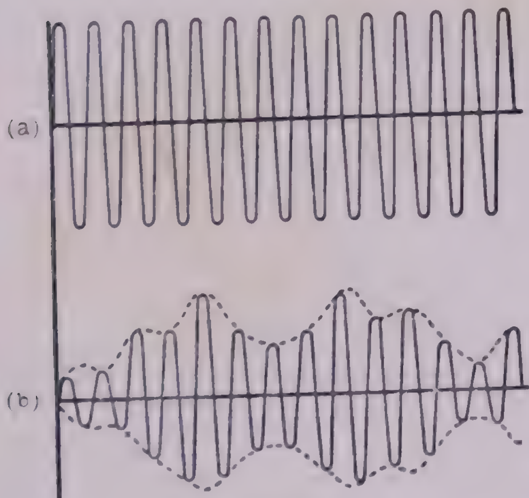


Fig. 103.

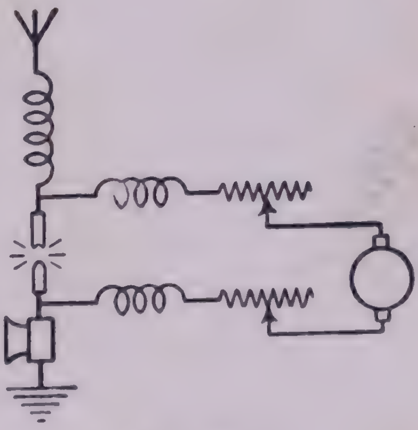


Fig. 104(*a*).

Fig. 104 (*a*) shows the principle of an arrangement for wireless telephony, the undamped or continuous waves being produced by means of an arc. The microphone is on the left near the earth connection. Other methods of arranging the microphone are employed (see later).

Another method of producing undamped oscillations and continuous waves for wireless telephony involves the use of a high frequency alternator. It is not an easy matter to make an alternator to work direct at such a high frequency and big output as are required for wireless, although machines are in use in transmitting stations giving frequencies of 30,000 and more cycles per second. The more usual method in practice is to employ high frequency alternators and then to increase the frequency by some special methods, *e.g.* by some type of **frequency changing transformer**. Thus the Telefunken Company have installed high frequency alternators, and have then multiplied the frequency of these alternators four times by means of frequency changing transformers.

The elementary principle of such a transformer may be given briefly as follows:—Imagine a bar of iron inside a solenoid and, starting with a very small (direct) current in the solenoid, let the current be gradually increased in strength. The bar, of course, becomes magnetised. Now at first the magnetism increases rapidly. Beyond a certain current value, however, the magnetism increases very slowly: in fact, beyond a certain point, when the iron is becoming what we call *saturated*, it requires an enormous increase in current to produce even a small increase in magnetisation.

Now suppose we have a transformer in which the iron core has been magnetised up to that particular point where saturation is setting in, and suppose the primary to be joined to a high frequency alternator. During one half cycle of the alternating current from the alternator, the current direction will be such that it tends to increase the magnetism, and as the iron is already near saturation the change in magnetism will be very small. During the next half cycle the current will be in the opposite direction tending to decrease the magnetism, and the change in magnetism will be great in comparison. The pressure induced in the secondary of the transformer due to this changing magnetism will therefore be much greater during this second half cycle than during the first half cycle, for the induced pressure is greater the greater the change in magnetism. The full line curve of Fig. 104 (*b*) shows this: it is much higher above the horizontal line than it reaches below it.

Finally, suppose we have two transformers of this nature and arrange them so that they are 180° out of step or out of phase; the full line of Fig. 104 (*b*) is the pressure curve for one and the dotted line of the same figure is the pressure curve for the other. Clearly, if we so arrange them that they both act on one secondary the resultant of these two curves will be as shown in Fig. 104 (*c*), and it will be apparent that the frequency of this pressure is twice that of the supply to the primaries. The arrangement has in fact doubled the frequency of the alternator supply. This is the principle of the frequency changing transformers used in conjunction with an alternator for the supply of undamped high frequency currents which in turn produce the undamped waves for wireless.

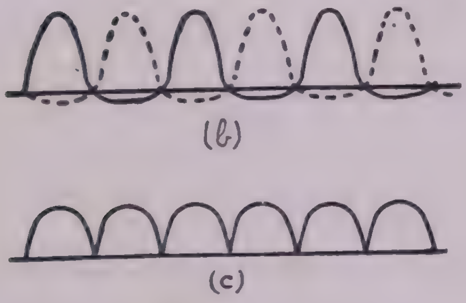


Fig. 104 (*b* and *c*).

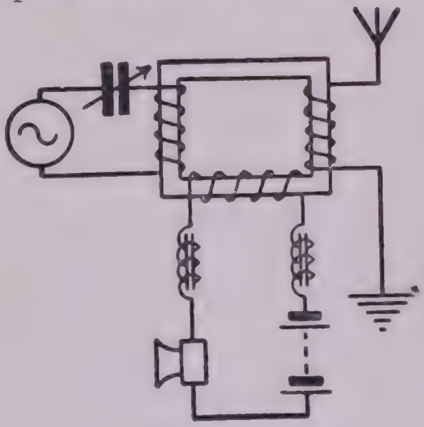


Fig. 104 (*d*).

A general idea of the preceding method as applied to wireless telephony will be gathered from Fig. 104 (*d*). The alternator (or frequency changing transformers to which the alternator is joined) is in the tuned circuit on the left, consisting of the primary of another transformer and a condenser. The aerial is connected to a secondary winding on the transformer, and the microphone is connected to a third winding on the transformer. When a person speaks into the microphone the changing microphone current varies the magnetic lines in the transformer, varies, therefore, the inductance of the other two circuits, and modulates, therefore, the induced aerial oscillations and the resulting waves according to the words spoken.

The preceding methods of producing continuous waves for wireless telephony are rapidly being replaced, however, by valve methods which will be dealt with later.

In modern practice it is found necessary to first amplify or magnify the microphone variations of potential in a manner which also will be understood later, but for the present Fig. 105 may be taken as a "bird's eye view" of the various links in the chain from the studio of the broadcasting station to the wireless receiver in the home.

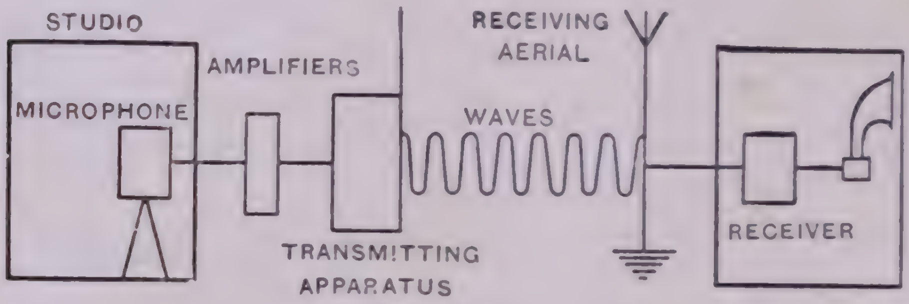


Fig. 105.

**94. Miscellaneous Facts about "Wireless" Waves.**—It is impossible at this stage of the reader's progress to explain fully the process of wave propagation through the aether from the transmitting station to the receiving station. The following gives only an elementary "skeleton" idea, and omits many very important points which the student can fill in when his studies have taken him into the higher branches of Physics; if the idea is difficult to grasp there is no necessity to worry about it at present.

Fig. 106 (*a*) depicts the electric lines of force say in Hertz's oscillator when it is just about to spark across the gap. When the oscillator begins to discharge the ends of the electric strain lines move along the rods, thus constituting the electric current, and at the same time magnetic strain lines appear as shown at $M$ in Fig. 106 (*b*): the outer portions of the electric lines are approaching the gap. Now the lines do not approach the rods as quickly as their opposite ends move along them, hence they take up the form shown in Fig. 106 (*c*). At a later stage the ends of the lines will have "crossed over" as indicated in Fig. 106 (*d*), and a closed strain loop will be thrown off as shown in Fig. 106 (*e*). The next "surging" will give rise to another set of closed loops (Fig. 106 (*f*)), and so on. It is this detachment of loops which constitutes electric radiation, the loops travelling outwards with a velocity of 186,000 miles per second. It will be noted that the direction of the electric strain is opposite in successive loops, and so also is the magnetic strain, the magnetic strain being, as already mentioned, at right angles to the direction of the electric strain, and both at right angles to the motion. This statement requires a slight modification for scientific accuracy, but the student need not trouble about this at present.

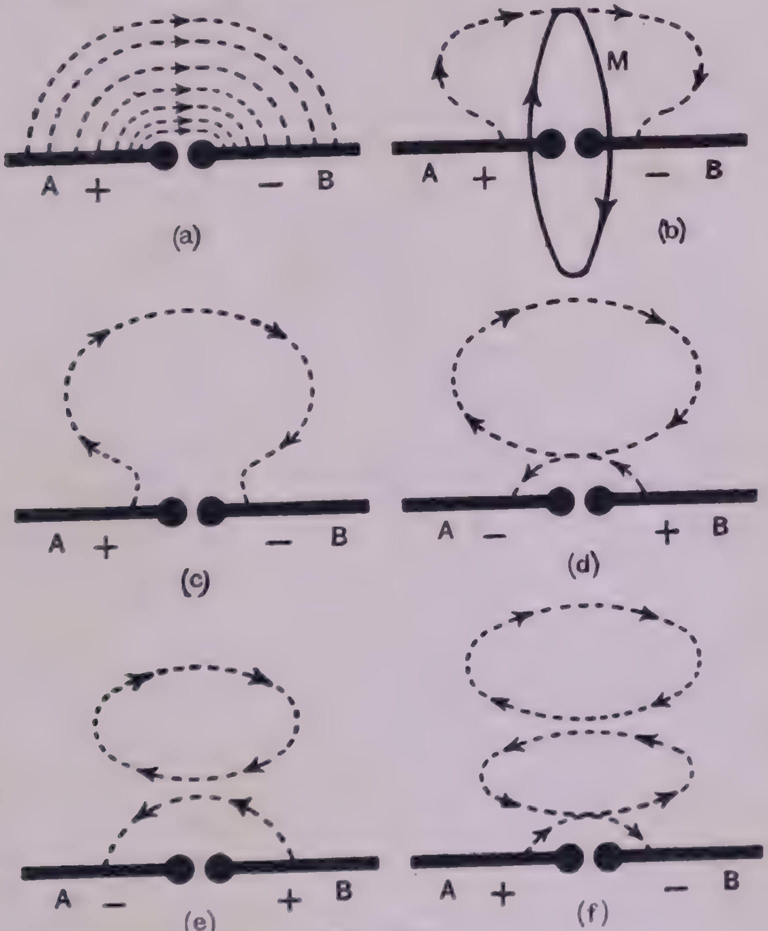


Fig. 106.

Instead of saying that the loops travel outwards, it would be more exact to say that a loop "dies" at one place and is "re-created" at another. Each electric strain line shrinks, in so doing creating magnetic strain lines, the rise and fall of which recreate loops of electric strain, and so on; hence the effect is equivalent to a progression through space of two sets of strain, electric and magnetic, which constitute the electromagnetic wave.

We would again emphasise a fact mentioned in Art. 90. Near the spark gap of the preceding figures the two disturbances—electric and magnetic—are not in phase, and energy pulsates in and out. A quarter of a wave length away they have got into step—the one is a maximum when the other is a maximum—and waves pass out with the velocity of light. The two disturbances are at right angles, and the direction of propagation is at right angles to both.

Fig. 107 will emphasise this latter point. Consider two closed loops as shown, $XY$ being normal to the oscillator at its mid-point, and the figure representing the condition at a distance beyond the quarter wave-length distance. At points such as $P$ the magnetic disturbance $H$ and the electric disturbance $F$ have their greatest values, at $Q$ they are zero, at $R$ they are again greatest but in the opposite direction to $P$, at $S$ they are again zero and so on. The magnetic force $H$ is at right angles to the electric force $F$, and both are at right angles to the direction of motion, but $F$ and $H$ are in step or in phase, both reaching their maximum and both their minimum together.

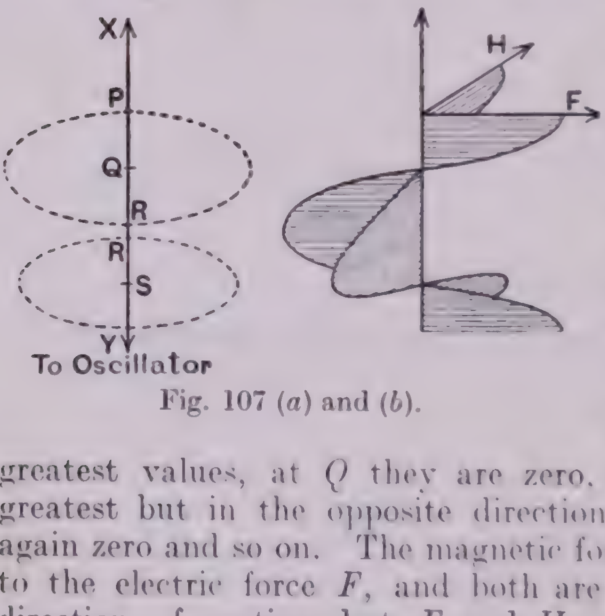


Fig. 107 (*a*) and (*b*).

In the case of wireless telegraphy and telephony, since the lower end of the radiating aerial is earthed the loops take the form shown in Fig. 108. Again, as the earth joins the feet of these half loops, currents flow through the surface layers of the ground: these are indicated in Fig. 109 which gives *the direction in which the electrons go*, *i.e.* from negative to

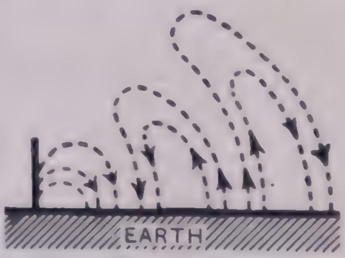


Fig. 108.

positive. For simplicity the loops are shown perpendicular to the ground in Fig. 109 (see below).

Now consider the waves of Fig. 109 arriving at a receiving aerial. As this aerial happens to join two points of the electric field at different potentials a current is produced in it. The top of the aerial being more positive than the earth end, electrons rush up from the ground and charge the aerial negatively. If the aerial is in tune with the transmitting station it will be just on the point of discharging itself when the next half wave arrives which, of course, will help the discharge and the recharge in the opposite direction.

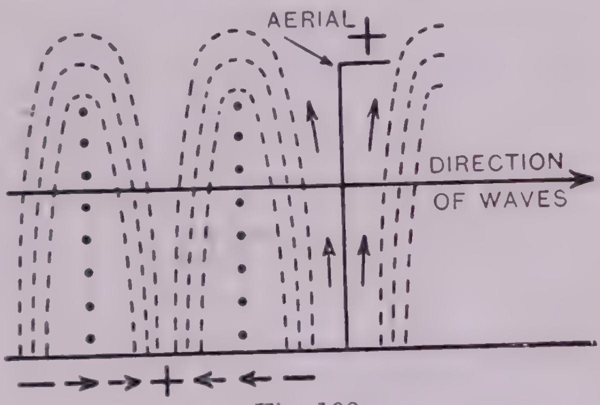


Fig. 109.

It is clear that if the earth were surrounded by a spherical conductor some distance away from it the waves would travel between this conducting surface and the conducting surface of the earth, and they would follow the curvature of the earth; that they do follow the curvature of the earth is well known, for we can signal half way round the earth and more.

Such a conductor does exist and it is known as the **Heaviside layer**. Owing to the action of the sun the upper regions of the atmosphere are what is termed **ionised**, *i.e.* positively and negatively charged particles are produced in it called *ions* (Art. 6) and the result of this is that a fairly well defined upper layer of the atmosphere is produced which acts as a very good conducting surface, just as the earth acts as a lower conducting surface, and it is largely owing to this that long signalling ranges are obtained in practice despite the curvature of the earth. It is owing to this good conducting layer that the tops of the waves travel faster than the feet, so that although the waves start out from the transmitting aerial with a "backward bend" as shown in Fig. 108, further on they assume a "forward bend" as indicated in Fig. 110.

The inconvenience of a purely vertical aerial is apparent, and in practice partially horizontal aerials as shown in outline in Fig. 110 are used. These are dealt with in Chapter VIII. As will be seen later, a rectangle of wire can also be used as an aerial, but it must be in a certain position with regard to the incoming waves, as the following reasoning will show. Consider the part rectangle of wire shown in Fig. 111 and imagine it to be placed with its face at right angles to the waves; in fact imagine the waves to be passing "into the paper." If at any instant the E.M.F. is upwards say in the side *B*, it will also be upwards in the side *A*; the two will cancel and the result will be nil. If the direction of the wave is indicated by *PO*, the conditions at *B* and *C* will be equal at any instant, but those at *A* will lag behind those at *B* and *C* by an amount depending on the distance *CA*. The actual E.M.F. will be the difference between the E.M.F.'s induced in *A* and *B* and will increase as *AC* increases, being a minimum when *PO* is at right angles to *AB* and a maximum when *PO* is in line with *AB*. In other words signals will be received when the plane or face of the coil is pointing in the direction in which the waves are coming, and no signals will be received when the plane of the coil is perpendicular to that direction. Such an aerial is called a loop or **frame aerial**, and is dealt with in Chapter IX.

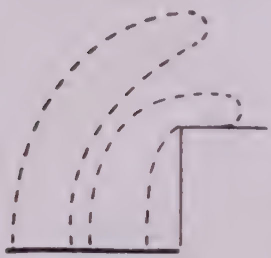


Fig. 110

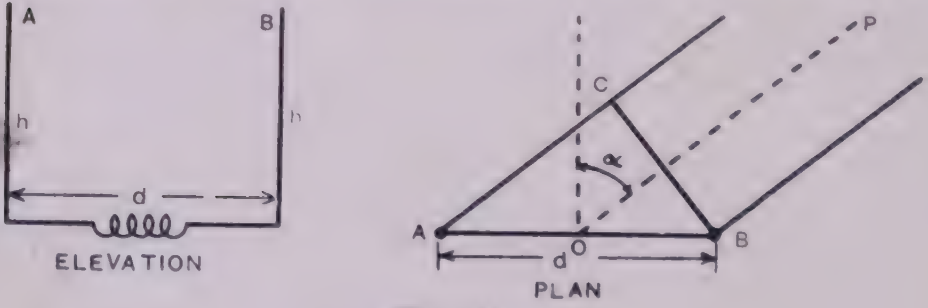


Fig. 111.

We have seen that, accompanying the propagation of the wireless waves, there are currents circulating in the surface layers of the earth, the energy being derived from the waves themselves, and it is clear that the energy dissipated in this way will depend upon the surface resistance. Dry soil has a very high resistance compared with sea water, hence wireless messages can be transmitted over the sea to a much greater distance than over land : sandy deserts are very difficult to signal over for any great distance owing to the high surface resistance : limestone too has a large resistance and tends to reduce signalling distance. Again, since the resistance of a conductor to high frequency currents depends on the frequency, being greater the greater the frequency, the loss referred to above will increase with the wave frequency : hence since the higher the frequency the shorter the wave length, it follows that, from this point of view, long waves will transmit signals to a greater distance than short waves.

It is a well known fact that the range of wireless signalling is greater at night than during the day. Here again, owing to the action of the sun, the lower regions of the atmosphere are to a certain extent ionised, and made more or less a partial conductor, which leads to a dissipation of energy and reduction in signalling distance. When the sun sets, recombination takes place between the positive and the negative ions, with the result that there is less absorption, less dissipation of energy, and signalling distance increases.

Abnormal electrical conditions in the atmosphere, e.g. lightning, sudden recombinations of ions, etc., affect the receiving apparatus ; these are known as **atmospherics or Xs**, and they often prove an utter nuisance in wireless reception. Generally speaking, there are three kinds of atmospherics, (1) those giving sudden, loud, ear-splitting clicks in the telephones, due to lightning somewhere within the range of the aerial, (2) those giving a persistent rattling noise, due to atmospheric changes such as ionisation or recombination of ions taking place above the clouds, (3) those giving a hissing noise, due to electrified clouds moving in the vicinity.

Good signals at night frequently follow a cloudy day, probably owing to the facts that the lower regions of the atmosphere have not been so strongly ionised during the day, and also that the earth's surface is moist.

Wet weather decreases the insulating properties of the aerial system, but at the same time improves the earth system. On hot dry days the lower regions of the atmosphere are highly ionised and the earth dry and of increased resistance; hence signal strength and distance are reduced.

Signalling between two stations so situated that when it is night time in one station it is day time in the other is often difficult. This is probably due to reflection, etc., in the twilight area—the part where there is a change from dark to light—caused by irregular ionisation of the atmosphere.

**Fading**, *i.e.* the dying down of a signal until sometimes it can scarcely be heard and then its rise again to normal strength, is another wireless nuisance, and one explanation is as follows. The Heaviside layer, as has been pointed out, is a layer of ionised air in the upper regions of the atmosphere which is a very good conductor. Now in Fig. 112 it will be seen that a receiving station *R*, tuned in to the transmitting station *T*, may be under the influence of two waves from *T*, one travelling direct along the earth and the other reaching *R* after reflection at the Heaviside layer. The former wave is more or less regular in character, but the latter, for reasons which cannot be explained here, is subjected to a certain twisting at reflection; moreover the two have travelled different distances. If these two waves meet at *R* in such a way that they help each other, *i.e.* if they meet, as it were "crest to crest and trough to trough," the signal will be strengthened, but if they meet so as to oppose each other the signal will decrease.

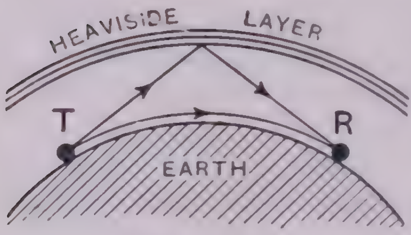


Fig. 112.

From the above the student will gather a general idea of one cause of fading: to go into further details would necessitate a lengthy discussion of wave interference in general.

From what has been said in this chapter the student will be prepared for the statement that light waves and wireless waves are identical in general character. They are both waves in the aether and they both travel with a velocity of about 186,000 miles per second. They differ only, in fact, in frequency and wave length, light waves being of greater frequency and shorter wave length than wireless waves. The wave length of the visible spectrum (*i.e.* the range of waves which affect the eye) varies from the shortest (violet) which has a wave length of ·00000043 metre to the longest (red) which has a wave length of ·00000075 metre. In the ultra-violet waves have been detected as short as ·0000001 metre, and in the infra-red as long as ·000061 metre possessing properties similar to the light waves which affect the eye. Some distance below the infra-red come the electromagnetic waves used in wireless which range in wave length from a hundred feet or so to several miles. The British broadcasting band of wave lengths ranges from about 300 metres to 600 metres. The Daventry high power station transmits at 1,600 metres and Eiffel Tower at 2,650 metres. Incidentally X-rays are waves in the aether very much shorter than ultra violet waves, and gamma rays from radio-active substances are still shorter. It must be remembered that the shorter the wave length the higher the frequency.

On page 134 is a list of the electromagnetic waves known to us, arranged in descending order of frequency and therefore increasing order of wave length.

In the early days of wireless, Hertz, Lodge, Marconi, Admiral Sir H. Jackson and others experimented with "short" wireless waves, but Marconi's "aerial and earth" discovery and the resulting greater range of signalling turned the attention of experimenters to "long" waves. Higher and longer became the aerials, and as the natural wave length of an aerial is roughly four times its own length, it will readily be seen how long waves became the order of the day. Thus for many years wireless engineers have been moving in the direction of high masts and long aerials and greater and greater power in order to transmit successfully these long waves over greater and greater distances.

Since the war attention has been directed once more to the possibilities of short waves, largely by the work of amateurs who were restricted to short waves (even below 100 metres) by Government regulations, and to-day short wave transmission has achieved wonderful success. Long distances have been covered, the power used being a mere fraction of what is used with long wave transmission, and further, short waves can be projected by parabolic mirrors of reasonable size so as to be concentrated in a definite direction like light waves from a lighthouse. Marconi is developing this in his recent "beam system."

**RANGE OF AETHER WAVES.**

| Wave. | | Approximate Frequencies (per second). |
|---|---|---|
| | Gamma rays | Hundreds of thousands of millions of millions |
| | X rays | ↓ |
| | Ultra violet | |
| Spectrum | Violet | 800 millions of millions |
| | Indigo | |
| | Blue | |
| | Green | |
| | Yellow | ↓ |
| | Orange | |
| | Red | 400 millions of millions |
| | Infra red | |
| | ↓ | ↓ |
| | Laboratory electric waves | 30 thousand millions |
| | ↓ | ↓ |
| | Short wireless waves | 3,000,000 |
| | Broadcasting band | 1,000,000—500,000 |
| | Long wireless waves | 170,000 |
| | ↓ | ↓ |
| | Longer waves from an alternator in an alternating current power station. | |

At present, however, short waves have not got the range *during the day* that long waves have, and moreover signals are often not heard within a distance of several miles, although they are quite distinct beyond that range; fading, too, seems more pronounced with short waves. On the whole there is little doubt but that short waves in wireless will come more and more into use in the future, but it is unlikely that short waves will ever entirely displace the long waves at present employed.

# CHAPTER VIII.

## THE CRYSTAL AND THE VALVE.

**95. The Crystal as a Rectifier.**—As already indicated, a crystal depends for its action as a "detector" on the fact that its conductivity is different in different directions (a current can pass through it in one direction but not in another), so that an oscillatory current impressed upon it will be changed more or less into a direct current by the crystal choking down the flow in one direction, and thus a telephone in the circuit of the crystal may be made to respond. With the crystal reception connections of Fig. 113, a unidirectional current passes through the crystal each time a group of oscillations is set up in the receiving aerial, *i.e.* each time a spark, say, passes at the transmitter (Art. 92).

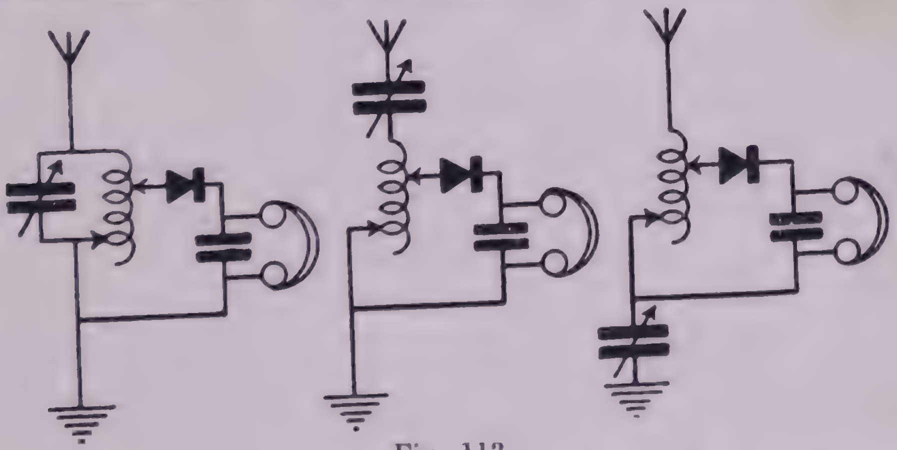


Fig. 113.

The note heard in the telephones in series with the crystal will therefore be of the same frequency as that of the sparks, starting and stopping when the operator at the transmitting station starts and stops the sparks. Thus intelligible messages can be transmitted. Crystal circuits are dealt with in detail in Chapter X.

The above explanation is true as far as it goes, but it does not say *why* a crystal should behave in this way. In broadcast reception about 100,000 pulses of high frequency current are applied in about $\frac{1}{10}$ of a second. Now the crystal is a bad conductor of electricity and a good retainer of heat compared with, say, any metal which may be making contact with it (*e.g.* the catwhisker). Clearly then the crystal will soon become fairly warm compared with the metal, and we shall have two substances at different temperatures in contact. Now in the theory of electricity it is shown that this sets up a voltage in one definite direction which, therefore, will assist the oscillatory current when it is flowing one way and oppose it when it is flowing the other way. This then may be *one* cause of the property of the crystal in question. Other circumstances, however, play a part, and the true explanation of the rectifying action is still unknown.

**96. Types of Crystals and Crystal Detectors.**—In a general way crystals may be divided into two classes, viz. (1) those which require a metal contact (generally in the form of a very fine wire), known as the "catwhisker" type, and (2) those which require another crystal contact, known as the "perikon" type. In the first class are silicon, iron pyrites, carborundum, galena, molybdenite, etc. In the second class are zincite, bornite, copper pyrites, tellurium, chalcocite, etc.: galena can also be used as a perikon. Most of the "ites" on the market, and also most crystals with other name endings, are galena subjected to various treatments, and many are really excellent.

Some crystals in the first class work best with certain metal contacts. Carborundum and silicon require steel: iron pyrites works best with gold: galena will work with gold, silver, copper, or brass: molybdenite is best with silver. Of the second class, zincite with bornite, and zincite with tellurium give good results. It is perhaps more difficult to find the sensitive spots with the perikon than with the catwhisker, but once set it is not so easily thrown out of adjustment.

There are numerous types of crystal detectors on the market.

In one form a small brass cup fixed at one end of a glass tube contains the crystal, which is held in the cup by screws or is fixed therein by Wood's metal (which melts at a low temperature). At the other end of the tube is a rod carrying a fine wire—the catwhisker : this rod can be moved to and fro or rotated so that the catwhisker can be put gently in contact with different points of the crystal surface. The cup and the rod are joined to the two terminals of the detector. For other types the makers' catalogues may be consulted.

Many " permanent " detectors are in use. These are merely some form of the preceding, but permanently fixed in a sensitive position so that no adjustment is necessary.

Carborundum requires a small voltage to be applied to it—about ·6 volt. This is usually done as indicated in Fig. 114. A wire (known as a *potentiometer*) is joined to a small battery and tappings are taken as indicated : the tappings are varied, thus varying the small voltage applied to the crystal, until the best results are obtained.

Crystals should not be heated to a high temperature, should not be touched with the fingers (use tweezers), should be insulated from earth, and their surfaces should be protected from dust.

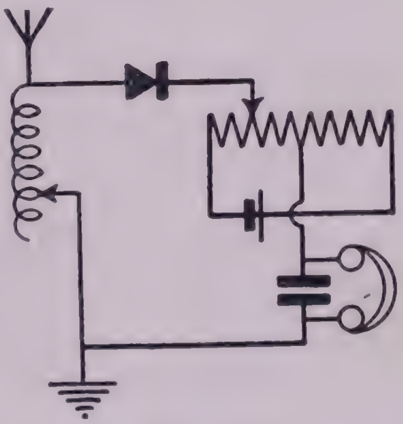


Fig. 114.

**97. The Thermionic Valve.**—Valves are largely used in wireless, for they can perform certain necessary operations better than any other known piece of apparatus, and the real reason they can do this is that they have a tremendous supply of electrons ; these electrons are emitted from a hot filament inside the valve.

An early type of valve known as the **diode** is shown in Fig. 115. It consists of a filament lamp fitted with an electrode *P* known as the **plate** or **anode**. When the filament is incandescent it emits (negative) electrons, so that if *P* is joined to the positive pole of a battery as shown, and therefore maintained at a positive potential, the electrons are attracted towards it. This movement of electrons from filament to plate constitutes an electric current from plate to filament, and the measuring instrument *A* will be deflected. If the cell connections be reversed the current stops. If an oscillatory pressure be used instead of a direct pressure from a battery, current will flow through the valve when the plate is positive but not when the plate is negative.

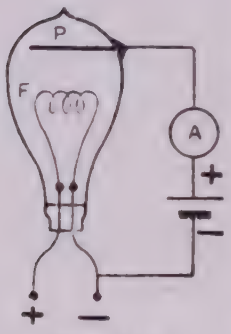


Fig. 115.

Thus we may say that the valve possesses *unilateral conductivity* similar to that of the crystal, inasmuch as current can only flow through it in one direction, and this indicates its possible use as a rectifier or detector in wireless. Note particularly that *in order to get a current through A and the lamp, the positive pole of the battery must be joined to the plate*: a current in this circuit is spoken of as a "plate current."

To explain the use of a valve in wireless one or two other statements must first be made. The electrons are emitted by the hot filament, and the higher the temperature the better the emission. The best material for the purpose is *tungsten*, and if this is used alone for the filament the valve is called a **bright emitter valve.** If *barium oxide* is added to the tungsten we get the necessary emission at a much lower temperature and the valve lasts longer: such a valve is called a **dull emitter valve** (see also p. 149). The number of electrons given off per second is enormous—several times a million times a million.

Again, the speed of the electrons is also enormous. Under the influence of the attraction of the positive plate they leave the filament with a speed of about 400 miles per second, but reach much higher speeds as they approach the plate.

The modern valve used in wireless and known as the **triode** consists of a tungsten filament *F*, and a plate *P*, with a wire **grid** *G* between them, the three being quite separate from each other as indicated in Fig. 116. Imagine that the plate and filament are joined to a battery

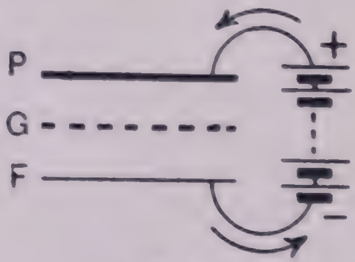


Fig. 116.

(from 50 to 100 volts in practice) as in Fig. 116, so that electrons are passing from filament to plate, and therefore a plate current is flowing through the valve from plate to filament.

Imagine now that the grid *G* between *P* and *F* acquires from some outside source a negative potential. It will repel the electrons coming from the filament and stop many of them from reaching the plate; hence the plate current will decrease. If the potential of the grid becomes positive it will attract the electrons and, (as *P* is at a higher potential in practice), they continue their motion to the plate; thus the plate current will increase. To summarise—lowering the grid potential reduces the plate current: raising the grid potential increases the plate current.

Fig. 117 really shows the effect of the grid potential on the plate current, potentials to the left of *O* being negative. Thus when the grid has the negative potential *OB* it stops all the electrons and the plate current is zero. As the grid potential rises to zero the plate current increases to the value *OA*, and as the grid potential becomes more and more positive the plate current rises according to the curve *ACDE*. Such a curve is called a **characteristic curve of the valve.**

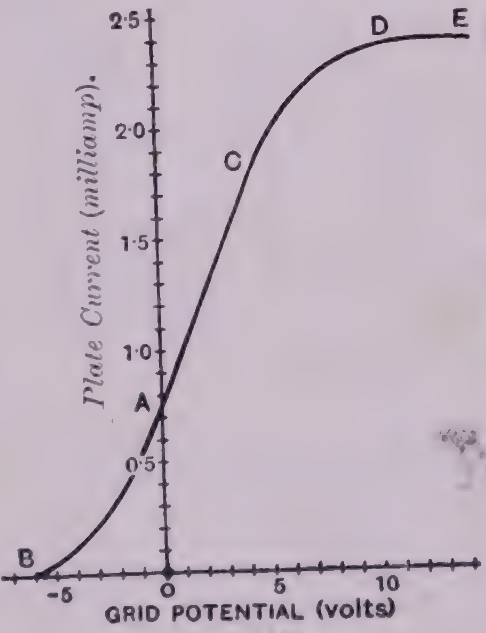


Fig. 117.

Another important point is that although the electrons are moving at such a high speed their mass is so small that if we *suddenly* change the voltage of the grid we get an *immediate* change in the stream of electrons and therefore in the plate current: there is no waiting,—a change in plate current *instantly* follows any change in the potential of the grid, however rapid the change.

There is no other mechanism which responds so quickly to changes. A telephone responds to sound waves in which changes are taking place up to 5,000 times a second, but it would not respond to anything of a much higher frequency. In wireless, however, the grid of a valve can be connected to an aerial circuit and be subjected to changes in voltages (due to the incoming waves) at frequencies of 10 million or 100 million per second, yet the flow of electrons will obey these rapid changes, thus causing corresponding changes in the plate current.

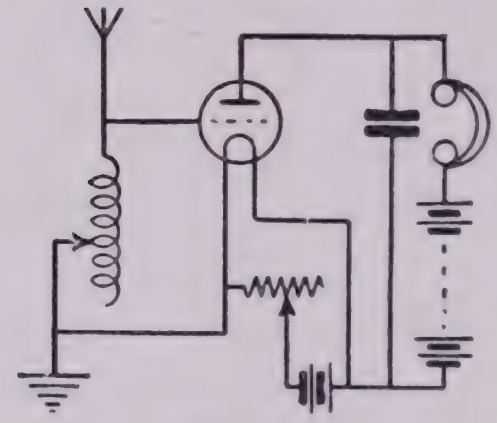


Fig. 118.

Fig. 118 shows the principle of the valve connections referred to above. The **high tension battery** as it is called (50 to 100 volts) is shown on the right, its positive pole being joined to the plate. The **low tension battery** (2 to 6 volts) for heating the filament is shown at the bottom of the figure (it has a variable resistance called a **filament rheostat** in its circuit to vary the current given to the filament). The grid is connected to the aerial circuit and other connections are as indicated. The rapidly changing or oscillatory potential differences set up in the aerial by the arriving waves are applied between the grid and filament, the electrons immediately respond, with the result that we have a corresponding change (really magnified) in the direct current in the plate circuit. The student should merely note the general connections at this stage; full explanations of valve circuits will be given later.

**98. Uses of the Valve in Wireless.**—In wireless reception the valve is used in two ways, viz. (1) as a **rectifying detector**, similar to the crystal, and (2) as an **amplifier**, *i.e.* a device for amplifying or magnifying the signals so that ultimately a louder sound is obtained. A valve used as a detector also amplifies, as is well known to those who have substituted a single valve receiver for a crystal receiver.

Again, an amplifying valve may be used to amplify the weak signals just as they arrive at the aerial, *i.e.* before they are passed on to the detector : this is called **high frequency amplification** for the signals are magnified at high frequency, and the method is used to bring in distant stations. A valve can also be used to amplify after the signals have passed through the detector and are suitable for telephone reception : this is called **low frequency** or **audio frequency** or **note amplification**, and is used to magnify the sound in the telephones or to enable a loud speaker to be used. The use of the valve as an amplifier will be considered first.

**99. The Valve as an Amplifier.**—Consider for a moment the steepest part of the characteristic curve of the valve shown in Fig. 119, and suppose the grid of the valve (when no signals are being received) to be at a potential represented by *OA*. A steady plate current will be passing, represented by *AF*. Now suppose wireless waves arrive and are conducted to the grid of the valve. These will vary the voltage of the grid, the positive half waves causing the grid potential to be higher and equal to *OB* say, and the negative half waves causing it to be an equal amount lower, *i.e.* equal to *OC*.

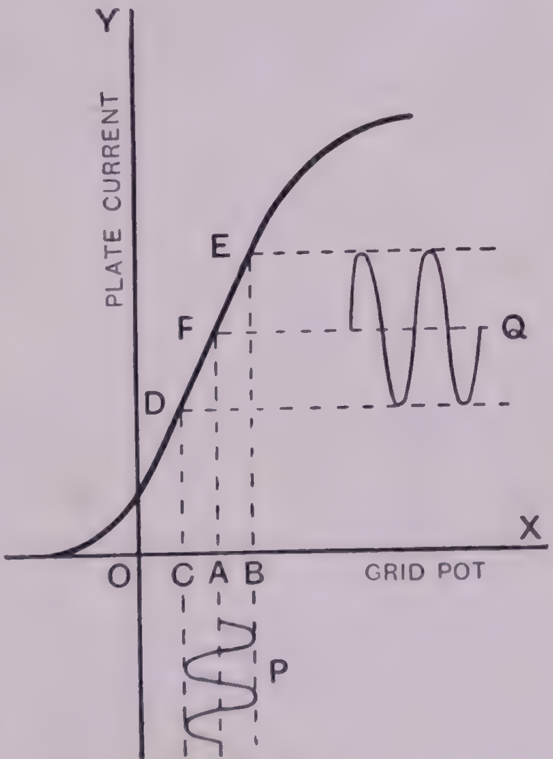
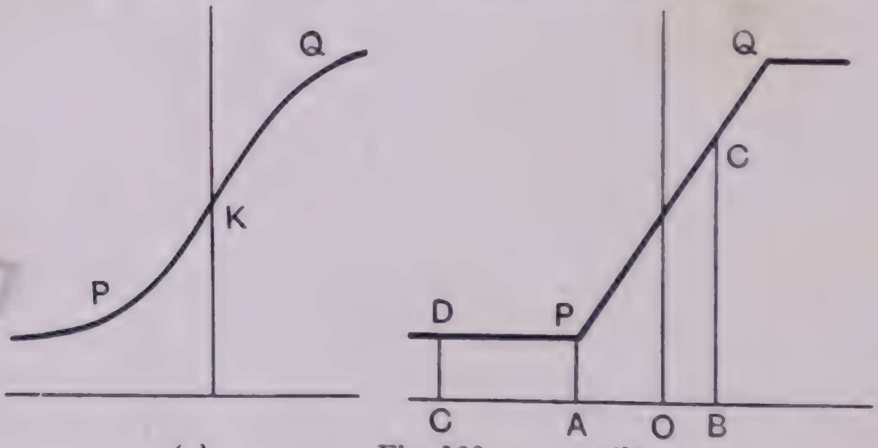


Fig. 119.

When the grid potential is *OB* the plate current will have increased from *AF* to *BE*, and when the grid potential is *OC* the plate current will have fallen to *CD*. Thus as the grid potential swings backwards and forwards (due to the arriving waves) between *OB* and *OC*, the plate current swings backwards and forwards between *BE* and *CD*, and further, the plate current changes follow the grid potential changes, and therefore the incoming waves, no matter how rapid the changes may be. As we are working on the steep part of the curve, however, a small jump from *C* to *B* causes a big jump from *D* to *E*, and this will be more pronounced the steeper the characteristic. It will be seen by comparing the two curves *P* and *Q* that the amplitude of *Q* is much bigger than that of *P*. Thus the valve has amplified the variations impressed upon the grid. In amplification the steep part of the curve is used. (The *amplification factor* is dealt with in Chapter XIII.)

**100. The Valve as a Detector.**—Consider now the parts of the curve where the bending is greatest, *i.e.* the "knees" *P* or *Q* (Fig. 120 (*a*)): to simplify matters we will exaggerate the knees as in Fig. 120 (*b*). With this curve, let the grid potential be equal to *OA* when no waves are passing, in which case the plate current is *AP*. When wireless waves arrive the negative half-wave lowers the potential of the grid to *OC*, but the plate current does not alter—it is *CD*, which is the same as its original value *AP*. When the positive half-wave arrives the grid potential rises to *B* and the plate current becomes *BC*. We thus get a plate current variation when the positive half-waves arrive, but not when the negative half-waves arrive.



(*a*) Fig. 120. (*b*)

The valve is therefore acting as a rectifying detector, *i.e.* responding, as it were, only to currents in one direction.

Similar results will happen if the valve works at the other knee *Q*. It will be observed that there is a certain amount of amplification at the same time. The point to note particularly, however, is that in this method of rectification or detection the bending part or knee of the curve is employed.

Another method gives greater amplification as well as detection, and is the one most often used. It really amounts to getting rectification at the point K or thereabouts, corresponding approximately to zero volts on the grid, but it is more difficult to explain clearly to a beginner.

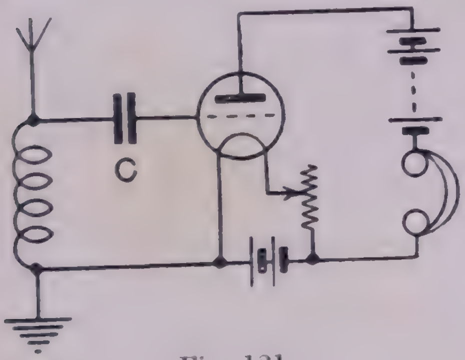


Fig. 121.

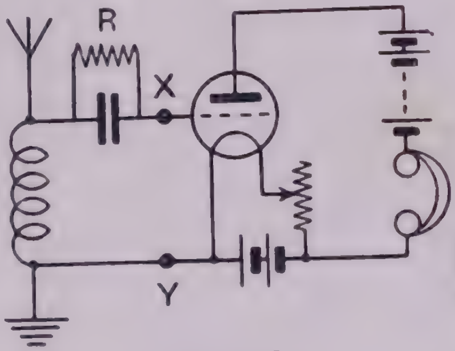


Fig. 122.

Consider the effect of putting a condenser *C* in the grid circuit as shown in Fig. 121, and imagine waves to be passing. High frequency impulses can of course pass through a condenser, but a direct current (direct flow of electrons) cannot. If the first half-wave is positive the grid will become positive; this will attract negative electrons from the filament which will neutralise the positive grid. If the condenser were absent any surplus electrons would be able to flow along to the aerial inductance and back to the filament, but they cannot do this on account of *C*, and so they stay on the grid, thus slightly lowering the grid potential.

The next half-wave is negative and this still further lowers the potential of the grid. The next half-wave is positive and the grid, as in the first case, gets a few more electrons. So the process goes on, the grid becoming more and more negative and its potential falling until it reaches a maximum negative value, when it will capture no more electrons. As the grid potential falls the plate current falls.

Now let the two coatings of $C$ be joined by a high resistance $R$ of one or two million ohms (called a **grid leak**) as shown in Fig. 122. This leak opens out a road from the grid to the filament *via* the aerial inductance, along which the accumulated electrons can escape from the grid when the latter has acquired a certain charge of electrons and is therefore at a certain negative potential. This escape of electrons brings the grid back to its original condition, and the action is repeated.

Fig. 123 roughly represents the conditions graphically. $O$ is the original potential point of the grid. The effect of the incoming waves $W$ is to lower the grid potential to $A$, the drop being represented by the falling line $OA$. From $A$ to $O$ the grid potential rises to the original value owing to the discharge of electrons through the grid leak.

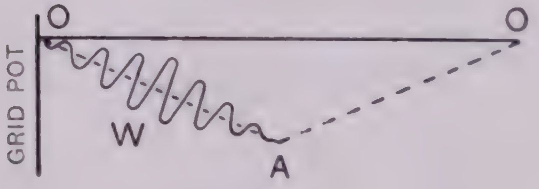


Fig. 123.

It will be seen therefore that each time a *group* of oscillations is received in the aerial the grid is left with a negative potential which gradually returns to its normal value, the accumulated negative electrons escaping through the leak when the (negative) pressure behind is sufficient to drive them through the leak resistance. The effect of this cumulative variation of grid potential is to produce a corresponding variation in the plate current: the average effect on the plate current is in fact represented by the area $OAO$, and it is a low frequency or audible effect: thus telephones can be used in the plate circuit.

If the detector valve has another valve in front of it the leak is connected between $X$ and $Y$ in Fig. 122: this is so that the condenser $C$ may protect the grid of the detector valve from the high potential plate of the first valve, which it could not do if $R$ were joined across it. This will be understood from the valve circuits which appear later.

The above is a very elementary account which omits many important facts, but it will answer the purpose at this stage of the reader's progress. Further, this and Art. 99 give general principles. The reader should, however, examine a few modern valve characteristics in the makers' catalogues. He will then all the better appreciate, when he comes to valve circuits in later chapters, why certain connections are advised to ensure that the valves are working on the best parts of their characteristics to suit the particular work they have to do.

**101. Types of Valves.**—The filament is usually a straight wire or loop of tungsten or thoriated tungsten.

The grid may consist of tungsten, nickel, or molybdenum in the form of a spiral or mesh cylinder surrounding the filament, or it may consist of two perforated plates one on each side of the filament, the two plates being connected together.

The anode or plate is usually of tungsten, nickel, or molybdenum, in the form of a cylinder surrounding the grid if the latter is cylindrical, or in the form of plates if the grid is in that form.

The bulb of the valve is exhausted : if completely exhausted the valve is called a *hard* valve, whilst if traces of gas remain it is called a *soft* valve. Glass bulbs are used for ordinary valves and silica for "power" valves (largely used in transmitting stations).

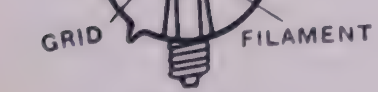


Fig. 124.

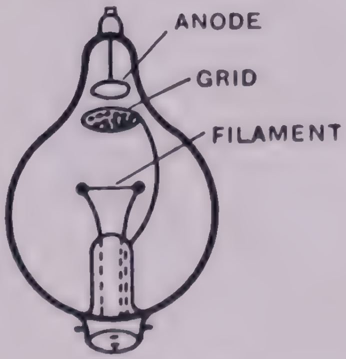


Fig. 125.

The **Lee de Forest Valve**—the original type of triode—is shown in Fig. 124. The filament was tantalum, the grid nickel wire, and the anode one or two nickel plates joined together.

The **White Valve** (Fig. 125) was largely used in the early period of the war. The filament was platinum coated with lime, the grid was a perforated copper disc, and the anode was a copper disc coated with mercury.

The **French Valve** (Fig. 126) was largely used towards the end of the war. The filament was a straight tungsten filament, the grid was a nickel wire wound in a coarse spiral, and the anode a nickel cylinder. The two ends of the filament, the anode, and the grid, were joined to four split pins in the base which were unequally spaced to prevent wrong connection when the valve was placed in the valve holder. This practice is now almost universal.

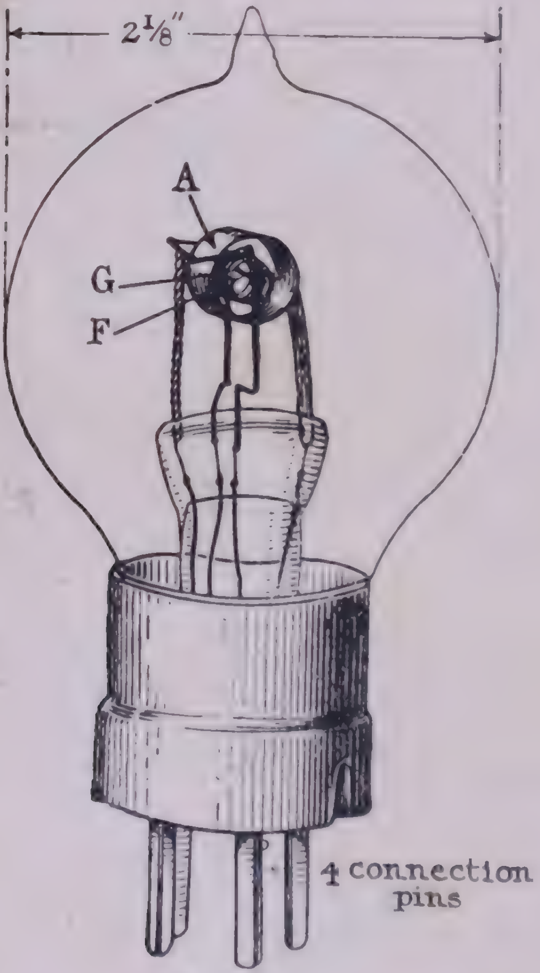


Fig 126.

Fig 127.

The **Ediswan AR Valve** (Fig. 127) is suitable either as a detector or as an amplifier. The anode is of the open ended cylinder type. The low tension battery or filament battery must give a voltage from 4 to 6, and the high tension battery a voltage from 30 to 80.

The **Cossor Valve** (Fig. 128) is fitted with an arch shaped filament surrounded by a hood shaped grid, this being again surrounded by a hood shaped anode. The P1 type is suitable for detection and low frequency amplification, and the P2 type for high frequency amplification. The filament volts are 4 to 4·5 and the high tension 30 to 120.

**Dull emitter valves** throw off electrons at a lower temperature than the preceding **bright emitter valves**. This means that a lower voltage is required on the filaments, and this means in turn a longer life for the valves. Some dull emitters require only about 1 volt on the filament, and in many cases cheap dry cells may be used with them instead of accumulators, thus reducing the initial cost and eliminating the cost of regular re-charging of accumulators.

On the other hand, dull emitters often produce what are known as *microphonic noises*: in some the least vibration produces a noise in the telephones, and the noise of a loud speaker itself has often been known to cause a wireless set equipped with such valves to give a continuous howl.

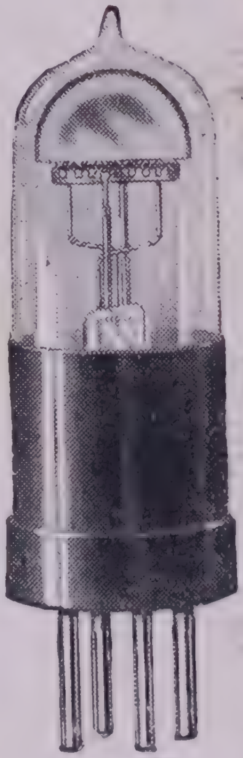


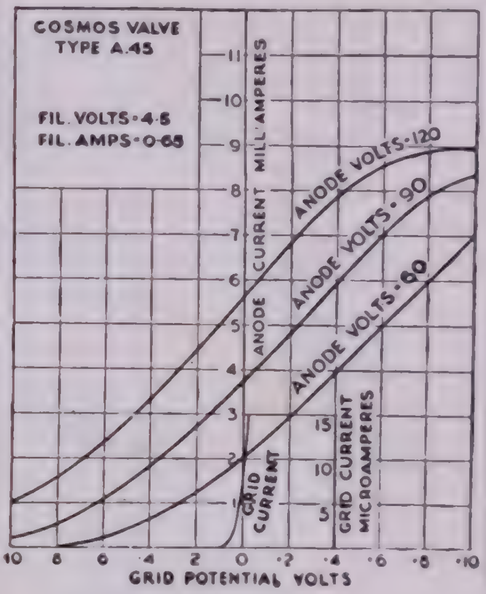
Fig. 128.

Several types of dull emitter valves are on the market. In one type the filament is a mixture of tungsten and barium oxide, whilst in another it is a platinum filament coated with a thin layer of material consisting of the oxides of the rare earths. Filaments of tungsten with an alloy of sodium and potassium are also reported to give good results.

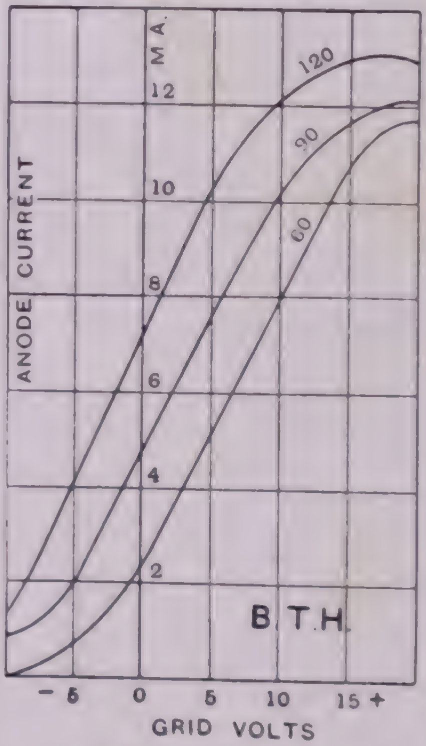
Other valves may be consulted in the manufacturers' catalogues.

The following particulars (pages 150, 151) of a few modern valves used in receiving circuits will be useful.

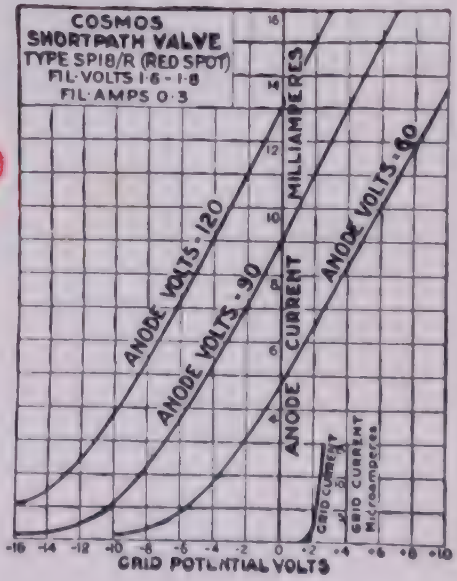
# TYPICAL MODERN VALVE CHARACTERISTICS.



(1) Comos General Purpose Valve Bright Emitter.



(2) B.T.H. Amplifying Valve Dull Emitter.



(3) Cosmos Amplifying Valve Dull Emitter.

## BRIGHT EMITTERS.

Use with 4 volt batteries :—

| Name. | Filament Current. | Filament Voltage. |
|---|---|---|
| Mullard Red Ring ... | ·6 | 3·2 |
| B.T.H. R. ... ... | ·63 | 4 |
| Mullard Ora A & B ... | ·65 | 3·4—3·8 |
| Marconi-Osram R.4C. ... | ·65 | 3·8 |
| Marconi-Osram R. ... | ·7 | 4 |
| Ediswan A.R. & R. ... | ·75 | 4 |

Use with 6 volt batteries :—

| Name. | Filament Current. | Filament Voltage. |
|---|---|---|
| Marconi-Osram R.5 ... | ·65 | 5 |
| Cossor $P_1$ & $P_2$ ... ... | ·75 | 4—4·5 |
| Marconi-Osram Q.X. ... | ·75 | 5 |
| Marconi-Osram V.24 ... | ·75 | 5 |
| Marconi-Osram F.E.1 ... & FE2 ... ... | 1·5 | 4—5 |
| Marconi-Osram L.S.1 ... & L.S.2 ... ... | 1·5 | 6 |

## DULL EMITTERS.

Use with 2 volt batteries :—

| Name. | Filament Current. | Filament Voltage. |
|---|---|---|
| Met.-Vick. D.2 ... ... | ·25 | 1·1 |
| Ediswan A.R.D.E. ... | ·3 | 1·8—2 |
| Cossor W.1 & W.2 ... | ·3 | 1·8—2 |
| Cossor W.R.1 & 2 ... | ·3 | 1·8—2 |
| Mullard D.3 H.F. ... | ·3 | 1·8—2 |
| Mullard D.3 L.F. ... | ·3 | 1·8—2 |
| B.T.H. B.3 ... ... | ·35 | 2 |

Use with 3 volt batteries :—

| Name. | Filament Current. | Filament Voltage. |
|---|---|---|
| Ediswan A.R.06 ... | ·06 | 3 |
| Mullard D.06 H.F. ... | ·06 | 3 |
| Mullard D.06 L.F. ... | ·06 | 3 |
| Economic ·06 ... ... | ·06 | 3 |
| B.T.H. B.5 ... ... | ·06 | 3—4 |
| Marconi-Osram D.E.3 ... | ·06 | 2·4—3 |
| Marconi-Osram D.E.Q. ... | ·2 | 3 |

Amongst suitable dull emitters for 4 volt batteries are B.T.H. B.5 (filament consumption ·06), Marconi-Osram D.E. 4 (filament consumption ·32), Mullard D.F.A. 0 (filament consumption ·35), etc.

B tore 42
Accession No : ......... 1705.
U.D.C No : 535.56/WVT
5-7-81

# CHAPTER IX.

## AERIALS AND EARTHS.

**102. Types of Receiving Aerials.**—The aerial is one of the most important features in the ordinary wireless receiver, and every effort should be made to erect the best possible aerial which circumstances allow. For the receiving sets ordinarily in use an outside aerial is always more efficient than an inside aerial.

Stranded wire is best for aerial construction, for it has good mechanical strength and also offers low resistance to the high frequency currents; a low resistance aerial means, of course, less waste of energy in the aerial itself. The usual material is copper, and the gauge known as $\frac{7}{22}$, *i.e.* the variety consisting of 7 strands of No. 22 S.W.G. copper wire, is very efficient. It is advisable to use enamelled wire to prevent corrosion due to the atmosphere. Phosphor bronze wire is also used if still greater mechanical strength is required, combined with low resistance. Thin copper strip and phosphor bronze strip are occasionally employed owing to the low resistance of the strip to high frequency currents.

Two of the most common types of receiving aerials are shown in Figs. 129 and 130 and are known as the **inverted L type** and the **T type** respectively. In the former, one end of the wire is supported by a mast or tree or another building, and the other end of the wire by some suitable point on the house in which the receiving set is used: a "down lead" (also of $\frac{7}{22}$ copper wire) joins the end of the horizontal portion to the receiving set inside the house. In the **T** type the down lead is taken from the *electrical centre* of the horizontal portion: if this portion is truly horizontal the electrical centre is the mid point, but if one end is higher than the other, the electrical centre is nearer the lower end.

The aerial, as has been indicated, forms part of the receiving set, and we have seen that the set, by means of inductances and condensers, must be "tuned to resonance" with the arriving waves. Now the aerial portion alone has its *fundamental or natural wave length* (which of course differs with different aerials) and would pick up signals, if used without any tuner, of the same wave length as its own natural wave length. If an **L** aerial and a **T** aerial be of the same horizontal length, the natural wave length of the **L** aerial will be double that of the **T** aerial.

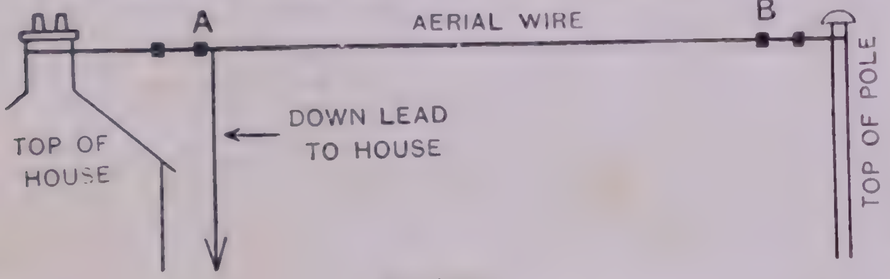


Fig. 129.

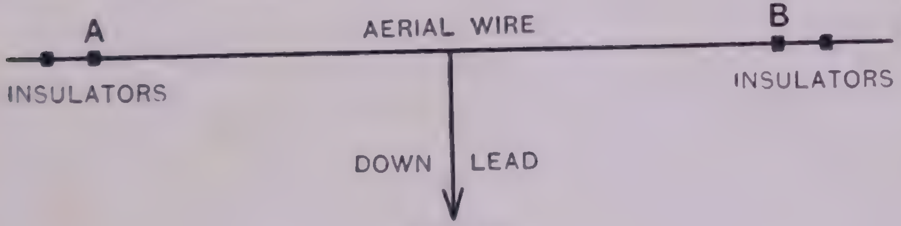


Fig. 130.

By the Post Office Regulations the total length of the horizontal portion together with the total length of down lead must not exceed 100 feet. For the British broadcasting band of wave lengths (say 300-600 metres) this total length has been found, theoretically and practically, to be suitable.

The question then arises as to how much of this 100 feet is best devoted to the horizontal portion and how much to the vertical portion, and in considering this it must be remembered that two results are desired in a wireless receiver, viz. **good signal strength** and **selectivity**. If an aerial and set are lacking in selectivity and if the set is tuned to receive waves, say of 300 metres, then not only will it be necessary to make a fairly large change in the tuning devices in order to cut out these signals (in which case the tuning is said to be "flat"), but a transmitting station operating on a different wave length may produce interference: this is particularly so with spark stations such as ships. On the other hand, if the set is selective, then not only will the slightest change in the tuning devices cut out the signals being received (in which case the tuning is said to be "sharp"), but stations operating on a different wave length will not interfere.

Now it is found that if the length of the aerial be reduced step by step the selectivity increases, but the signal strength somewhat decreases, and in practice a compromise must be made. From theoretical considerations it can be deduced that for satisfactory results the height of the ordinary receiving aerial should be as great as possible up to a maximum of about 60 feet, the balance being in the horizontal portion, and this has recently been verified experimentally by Mr. J. H. Reyner of the Radio Press. **Height is thus a primary consideration.** An aerial 37 feet high and 63 feet long is better than one 20 feet high and 80 feet long.

The aerial should be kept well above all surrounding objects such as trees and roofs of buildings, for these not only reduce the effective height but they absorb energy from the waves and thus exert a "screening" effect on the aerial: they also re-radiate energy, but there is not much reliable information on this point. Similarly an aerial passing along a passage between the gable ends of two houses—an arrangement frequently seen—is not efficient owing to the screening effect of the houses. If telephone or telegraph wires are in the vicinity it is best to arrange that the aerial is at right angles to them if possible.

In some cases a **twin wire** aerial (Fig. 131) of either the inverted **L** or **T** type is employed, especially if the space available is unusually short. The wires should be from 4 feet to 6 feet apart, being kept at this distance by wooden **spreaders**. Silver spruce is a suitable material for these. An insulator is fixed to the exact centre of the rope *R* and the lanyard *L* is attached to this insulator.

The natural wave length of multiple aerials is increased owing to the greater capacity, for although the inductance is less the increased capacity predominates. For ordinary reception purposes, however, single aerials are to be preferred in most cases.

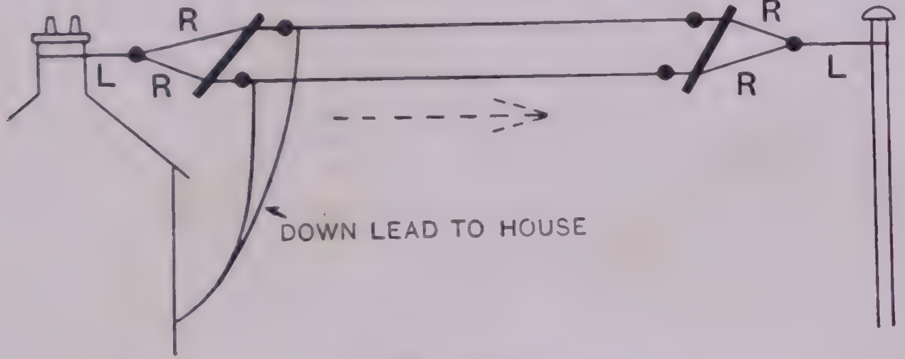


Fig. 131.

**103. Insulation of Aerials.**—It is essential that the aerial should be thoroughly insulated to prevent leakage of current. Two or three porcelain shell insulators should be used at each end, these being from 8 inches to 12 inches apart according to the space available (Figs. 129, 130). Other types of insulators may be used, the essentials being that they must be mechanically strong and present a good length of good insulating material between the wires passing through the holes at each end. Pyrex glass insulators are excellent in both these respects, but they are somewhat more expensive than the porcelain shell type.

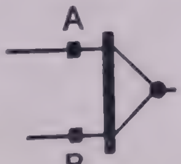


Fig. 132.

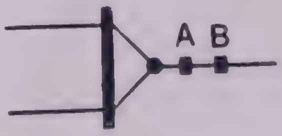


Fig. 133.

In the case of twin aerials the usual method of insulating is as indicated in Fig. 131. (Two insulators at each end of each wire are of course intended, but only one is shown for simplicity in the figure.) Referring to Fig. 132, however, it will be seen that the two insulators *A* and *B* form a parallel arrangement, whilst in Fig. 133 they form a series arrangement. The total resistance to leakage of current is therefore *much greater in the second arrangement.* Hence some experimenters combine the two methods. The method of Fig. 132 is, however, quite satisfactory if precautions be taken.

**104. The Down Lead.**—The horizontal part of the aerial is of course the part between the insulators *A* and *B* (Fig. 129). The down lead of Fig. 129 starts from the insulator *A* and should be *continuous with* the horizontal portion *AB*, *i.e.* instead of using a separate down lead and soldering it to the horizontal near *A*, the one aerial wire should be knotted or otherwise secured to *A*, one portion of the wire thus forming the horizontal and the other portion the down lead. In the case of the twin aerial, down leads are taken from each and then soldered together so as to constitute a single lead into the house (Fig. 131).

It is necessary that the down lead should be kept at least 3 feet from the building—the more the better—throughout almost the whole of its length. It should either run straight down or slope slightly towards the house: the efficiency is reduced if the down lead slopes backwards under the aerial.

The end of the down lead should be attached to a long insulated "lead-in" passing through a hole in either the window frame or the wall, and preferably vertically below the aerial if this is possible. The lead-in tube should be thick and should project at least four inches—*more if possible*—at each side of the wall. It is better to ensure a good connection between the down lead and the conducting core of the lead-in by soldering, but this is rarely done.

Inside the room, the receiving set should be placed as near to the lead-in as convenient, so that the connection between the lead-in and the aerial terminal of the set may be as short and as straight as possible. A long trailing connection between lead-in and set, or a long connection attached to the walls is not efficient—the latter is decidedly bad.

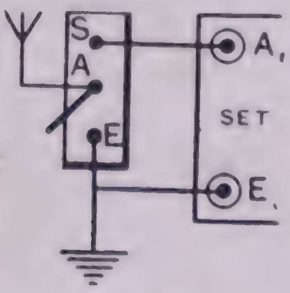


Fig. 134.

In all cases, as a protection against lightning, it is wise to use an earthing switch fixed to the wall or window **outside the house**. In this case the down lead, instead of being taken direct to the lead-in, is taken to the terminal *A* (Fig. 134) of the switch and the connection is soldered; similarly terminal *S* is soldered to a connector to the lead-in, whilst *E* is soldered to a connector to earth. When the switch arm is turned to $S$ the aerial is joined to the set: when it is turned to $E$ the aerial is disconnected from the set and safely earthed. Earthing switches should have large thick insulating bases, the distances $A$ to $S$ and $A$ to $E$ should be fairly long, and preferably the whole should be protected from rain, etc.

105. **Earth Systems.**—The earth system as well as the aerial forms part of the receiving set and equal care must be bestowed upon it. A usual earth for most receiving sets consists of a metal plate about 2 feet square, buried either vertically or horizontally to a depth of 3 feet or 4 feet immediately beneath the aerial and near the house. The earth lead from the set should be heavy gauge and insulated, and should be as short as possible. An insulated lead-in passing through another hole in the wall or window frame must be used just as in the case of the aerial. The earth wire must be soldered to the metal plate. Incidentally, terminal $E$ of the earthing switch referred to above may be joined to this same earth plate.

The soil in the vicinity of the plate must be kept damp. To secure this it is usual to fix one or two vertical tubes, the sides of which are preferably pierced with holes, over or near the plate, their upper ends projecting above the ground. In dry weather water can be poured down these tubes and the soil immediately surrounding the plate kept moist. Several "earth tubes" based on this principle are now obtainable. Two or three buried plates or earth tubes all connected together may be used if a greater surface of metal exposed to the soil is desired.

If a *main* water pipe or tap is suitably situated near the earth lead-in, the earth wire may be attached to it either by soldering or by means of a clamp, and this arrangement forms a good earth for ordinary reception purposes. A pipe or tap connected merely to a cistern and not to the main water supply will not answer the purpose: similarly a gas pipe does not make a good earth.

Another earthing method is that sometimes referred to as the "capacity earth." This consists of a good stout bare wire equal in length to the aerial laid along the ground exactly underneath the aerial, the far end being soldered to a metal peg about 3 feet long driven well down into the ground. Sometimes a modification is made, the wire being laid about 6 inches below the surface of the ground throughout its whole length. A still better arrangement is to use say three buried wires, one under the aerial and one on each side parallel to, and from 4 feet to 6 feet away from, the central wire, the three being joined together at the house end and a lead taken thence to the receiver. The plate or plates buried in moist earth combined with a short, thick, insulated earth lead is, however, more convenient in most cases.

**106. The Balanced Aerial or Counterpoise.**—Instead of the usual earth the **balanced aerial** or **counterpoise** arrangement may be adopted. The method where a single wire aerial is employed is indicated in Fig. 135. In the figure *C* is a wire of the same length as the aerial *A*, situated vertically beneath it at a height of 6 or 7 feet above the ground, and insulated and supported in the same way as the aerial itself: from the house end of *C* a lead passes in the usual way to the earth terminal of the receiving set.

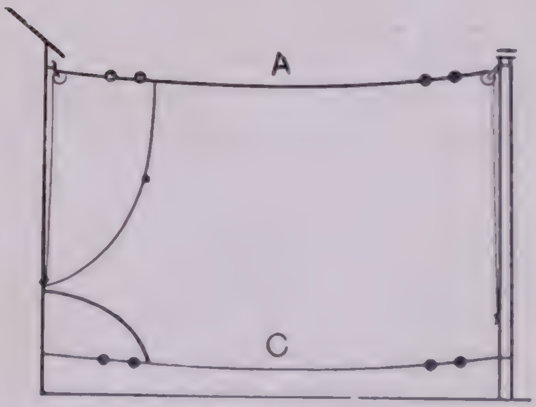


Fig. 135.

In the aerial and earth system we really have a condenser which acts as a collector of energy, one coating being the aerial and the other being the earth: in this system we also have a condenser acting in the same way, one coating again being the aerial whilst the other is the counterpoise *C*.

The counterpoise both for transmission and for reception has many supporters, particularly for medium and short waves, and a number of stations have now been fitted in this way. For reception purposes in private houses it is not so convenient to arrange as the earth plate system, but cases of poor reception, particularly as regards selectivity, have been known to be improved considerably by its adoption.

**107. Indoor Aerials.**—Some people, *e.g.* dwellers in flats, are unable to erect an outdoor aerial and in such cases an **indoor aerial** must be resorted to. A good type is easily constructed as follows :—

To the wall or picture rail at one end of a room three hooks are fixed, and to each hook a piece of string is attached, the other end of each string carrying an insulator : the hooks should be about 4 or 5 feet apart. This is repeated at the opposite wall of the room. A length of aerial wire is then fastened to the central insulator at one wall, carried across the room and attached to the central insulator at the other wall, the remainder of it forming a down lead to the set. Similarly two aerial wires are stretched across the room between the other insulators, the down leads of these being attached to the central down lead and soldered, thus giving the **V** formation and single connector to the set after the manner indicated in Fig. 131. Many other arrangements of indoor aerials are in use.

Within a distance of four or five miles from a main broadcasting station the aerial described above will give very good results even with crystal receivers. For greater distances the results are, in a general way, about 30 to 40 per cent. of what an outdoor aerial will give. It is of course best to have the aerial wires in an upper room of the house.

**108. Frame Aerials.**—With very powerful valve receiving sets and with super-sonic heterodyne sets (see Chapter XII.) what are known as **frame aerials** may be used. One form—the **box type**—is depicted in Fig. 136. To a suitable wooden base a vertical bar of wood *A* about 4 feet 6 inches long is fixed, carrying at a point 3 inches above its centre a horizontal bar of wood *B* about 4 feet long. Attached to each end of *B* and to the top of *A* are short rods of vulcanite *V*, each provided with six saw cuts at least $\frac{2}{5}$ inch apart : a similar piece of vulcanite *V* passes through a hole in *A* 6 inches from the bottom as indicated. *X* is a piece of vulcanite fitted with two brass terminals.

Six turns of bare or insulated copper wire of 18 to 26 S.W.G. are wound continuously on the frame, the beginning of the wire being fixed to one terminal on $X$ and the end to the other terminal on $X$. These terminals are joined to the aerial and earth terminals of the receiver when the set is in use. The dimensions given are suitable for the usual broadcasting: for long waves more turns of wire will be advisable.

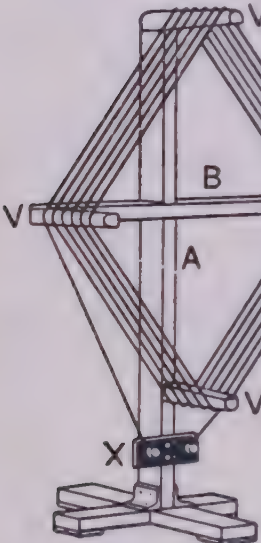


Fig: 136.

Another type of frame aerial is the **diamond type**. This somewhat resembles the box type in general appearance, but the winding is a flat coil, *i.e.* all the turns lie in one vertical plane, each turn being larger than the one which precedes it, as roughly indicated in Fig. 137.

The frame aerial is what is called **directional** in its reception, *i.e.* it responds to signals when it is placed in one position with regard to the incoming waves, whereas it does not respond when placed in another position. The theory of this has been given in Chapter VII., where it is deduced that for maximum reception, *i.e.* for a maximum current to flow in the aerial, the plane of the frame (or the bar $B$ in Fig. 136) must be pointing towards the transmitting station (Fig. 138 ($a$)): if the frame be turned through an angle of 90° so that the plane of the frame is, so to speak, broadside on to the station, *i.e.* at right angles to the direction of the station (Fig. 138 ($b$)) the reception is a minimum.

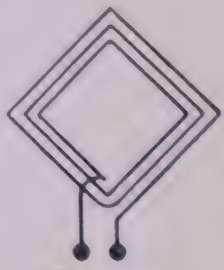


Fig. 137.

Clearly such an aerial may be used to find the direction in which a transmitting station is situated. The frame and set are tuned to the arriving waves and the frame turned until the reception is either a maximum or a minimum: in the former case the plane of the frame is pointing along, and in the latter case at right angles to, the direction in which the station lies.

The box aerial has better directional properties than the diamond aerial. Thus with the diamond type in the maximum position shown in Fig. 139 (*a*) coil 2, being in the same plane as coil 1, is almost shielded by it and therefore picks up little energy: with the box type in the maximum position, however, (Fig. 139 (*b*)) coil 2 is not shielded by coil 1, but is fully presented to the waves in the same way as coil 1. Clearly then the box type will give the better signals in the maximum position. Similarly with the diamond in the minimum position (Fig. 140 (*a*)) coil 2 is not shielded by coil 1, but with the box in the minimum position (Fig. 140 (*b*)) coil 2 is shielded by coil 1. Clearly then the box type tends to pick up less energy in the minimum position than the diamond type, *i.e.* the box type gives the weaker signals in the minimum position.

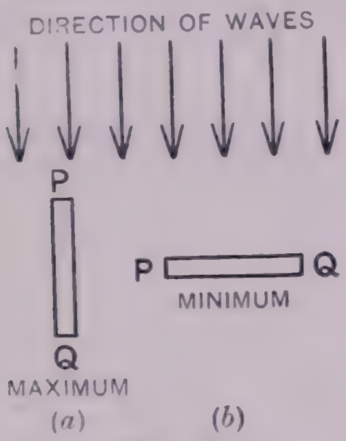


Fig. 138.

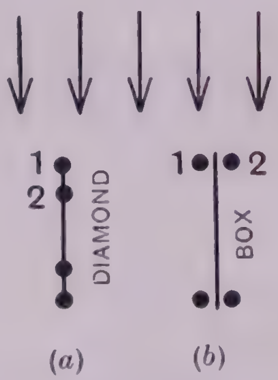
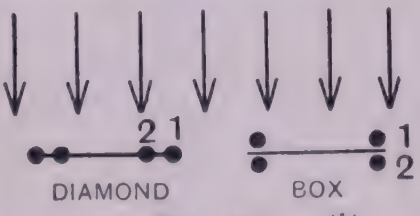


Fig. 139.



(*a*) Fig. 140. (*b*)

The preceding explanation is only of an elementary character, but it will help the student to grasp the essential facts. Obviously in working with a frame aerial it must be slowly rotated until the signals are at their maximum strength.

Incidentally it may be mentioned that the ordinary outdoor aerial, say the inverted **L** type, has directional properties to a certain extent. It gives preference to signals coming at its " nose " or lead-in end, as indicated by the dotted arrow in Fig. 131 : in other words it gives the best results if it points directly away from the transmitting station.

**109. Other Aerials and Earths.**—Multiple inverted **L** type and **T** type aerials are shown in principle in Fig. 141. The wires forming the flat roof are insulated and supported in practice as previously indicated.

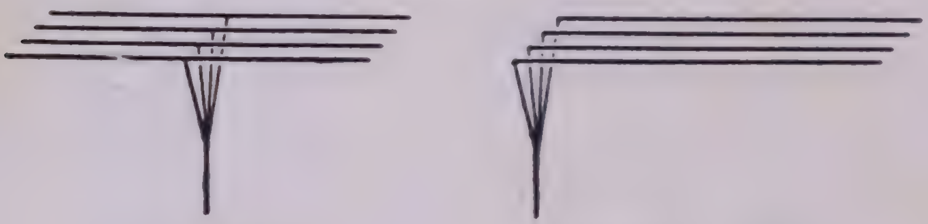

"T" Type. "Inverted L" Type.

Fig. 141.

In many cases a **sausage type** aerial (Fig. 142) is employed instead of a flat roof aerial, although more so in large stations than in ordinary private houses. In this type a number of wires in the form of a cylinder are used, circular spreaders of some sort being employed to keep the wires apart : these spreaders need not be insulated, for all the points on the wires joined to the same spreader are at the same potential. Further, a number of these sausages may be used to form a roof aerial (after the manner of Fig. 141) where a large capacity is required, *e.g.* in a transmitting aerial. Incidentally in a

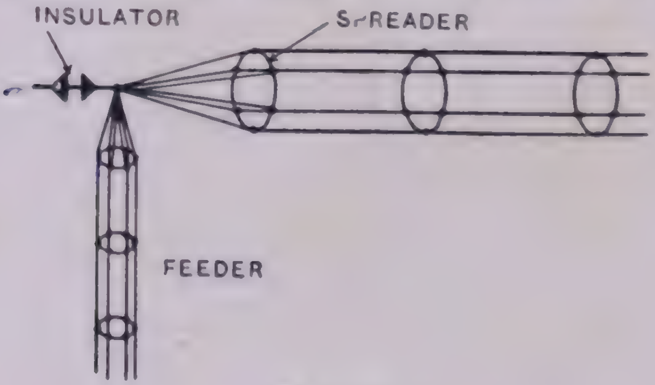


Fig. 142.

transmitting station the portion leading from the station to the roof is termed the *feeder*, for it is along this that the high frequency oscillating currents are fed into the aerial.

In the new P.O. wireless station at Rugby there are 12 masts each 820 feet high spaced a quarter of a mile apart round the edges of the station site, which is 1½ miles long and nearly 1 mile wide: the aerial runs approximately round the circumference of the site, passing from one mast to the next. The aerial itself consists of eight phosphor bronze wires, arranged as a cylinder 12 feet in diameter of which the axis is a steel rope: the wires are supported by spiders or spreaders, each after the style of the spokes of a bicycle wheel, threaded upon the rope at equal distances apart.

Another type of aerial is the **umbrella type** shown in principle in Fig. 143. This consists of one central mast with a number of aerial wires arranged around it, the wires really also acting as supporting stays: each wire is of course insulated from the mast and from the ground. A modified form of this is used in the German transmitting station at Eilvese, the central mast being 820 feet high.

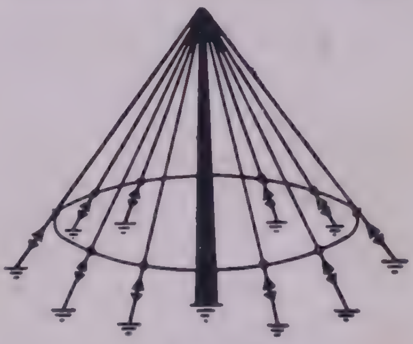


Fig 143.

In commercial wireless stations for transmission and reception various types of masts are in use. For the smaller stations tubular metal masts built in sections are usually employed. For the larger high power stations wooden lattice masts, as they are called, supported by guys, and rigid steel towers are used. Masts are sometimes well insulated, but frequently well earthed, since it is a difficult matter to thoroughly insulate such heavy constructions. In the new Rugby station, however, the steel lattice masts are insulated, Norwegian granite being used for the bulky portion of the insulating feet and porcelain "cheeses" for the part requiring the greatest electrical strength.

It is customary to divide mast stays into sections by insulators and to thoroughly earth the lower ends of the stays.

The directional properties of the frame aerial which is the main directional type used for *ordinary* broadcast reception purposes, and therefore the only type of importance to the student at this stage of his progress, have been dealt with in Arts. 94 and 108. There are, however, other arrangements which are specially designed not only for directional reception but also for directional transmission. Thus in some cases a wireless station for telegraphy and telephony is intended to work with only one other station, and in such a case directional transmission is desirable.

Again, during the war it became necessary to locate enemy wireless stations, and it is always important in peace as well as war for a ship or aeroplane to be able to determine its position relative to some fixed station, and in such cases directional reception is desirable. As already mentioned, however, these special "aerials" are not of importance to the student at this stage, and a description of them is consequently left over to the last chapter.

The earthing arrangement in large stations is a matter of vital importance. In practice earth wires are invariably run radially from the station over the whole of the "wireless area," and frequently a little beyond it. Sometimes the wires are totally buried in the ground: sometimes they are supported several feet above the ground and connected to earth plates at the far ends: sometimes again they are not earthed at all, in which case they form the lower portion of a balanced aerial system (frequently referred to as an **aerial screen**).

In the French station at Sainte-Assise a **T** aerial is employed, supported by 16 steel lattice masts. There are 42 earth plates, 16 being at the feet of the masts and 26 distributed under the aerial. The earth plates are connected to the station by 12 collecting wires which run the entire length of the aerial at a height of 16 feet above the ground.

At the Dublin station a **T** aerial is also employed. Symmetrical with the aerial is a continuous ring of earth plates buried vertically with their upper edges level with the surface of the ground: this earth ring is 70 feet in diameter. Buried earth wires spread out from the earth circle well beyond the extent of the aerial. At the centre of the earth circle is a short pole, and from insulators on the top of this pole a cone of wires radiate, making connection to the earth plates. From the apex of this cone the main earth connection passes to the transmitting apparatus in the station.

In those large stations which handle large currents at high voltages, very special attention must be paid to the many points (and others) mentioned as of importance in ordinary reception. Great height is essential for good radiation. There must be low resistance to reduce waste of energy in the conductors, and large capacity to permit of large oscillations of energy. Insulation must be of a high value to prevent leakage of current. Earthing must be very good indeed (for the current has its maximum value really at the earth end of an aerial). The natural wave length should be as nearly as possible equal to that of the wave to be transmitted. It is obvious that the complex aerial and earth systems employed in large stations embody the same general principles as those given for reception in the earlier part of this chapter.

R. B. A. N. M'S EDUCATIONAL CHARITIES.
No.........................
Date.........................
BANGALORE.

# CHAPTER X.

---

## CRYSTAL RECEIVING SETS.

**110. Introduction.**—Despite its limitations many people will always favour the simple crystal set for broadcast reception if they are so situated that a local station or the high power station at Daventry comes well within the crystal range. The initial cost of even the best constructed set is very small, and the maintenance expenses are negligible, for there are no valves to be broken or burnt out, no dry batteries to run down and be replaced, no accumulators to be regularly recharged. Crystal sets are simple to operate. Interference from neighbouring valve sets, ships, etc. is very much less than is experienced with valve receivers, and reproduction is purer. "Crystal purity" has in fact become a standard expression in the wireless world.

Crystal sets have their disadvantages, for when used under ordinary conditions they do not amplify or magnify the incoming signals as a valve does. Thus crystal sets can only be effectively used within comparatively short distances of a broadcasting station. No rigid statement can be made on the question of this distance, for with crystal sets so much depends on the efficiency of the earth and aerial systems. With such sets, which depend entirely on the small amount of energy received by the aerial system, the slightest loss must be avoided. Generally speaking, the distance at which a crystal set can be really efficiently operated is about 14 to 20 miles from a main broadcasting station and about 4 to 6 miles from a relay station, but with well made sets and under favourable conditions, these distances have been *very considerably* increased. From the high power station at Daventry crystal range is much greater—of the order 100 miles or more.

**111. Typical Crystal Circuits.**—Various wiring circuits may be employed in crystal receivers, these differing from each other mainly in the arrangement of the inductances and capacities, and the methods of varying these so as to tune the set to the particular wave length which is to be received.

Fig. 144 shows the connections of a very simple **variometer crystal receiver** for reception on the broadcast band of wave lengths and also on the higher wave length from Daventry.

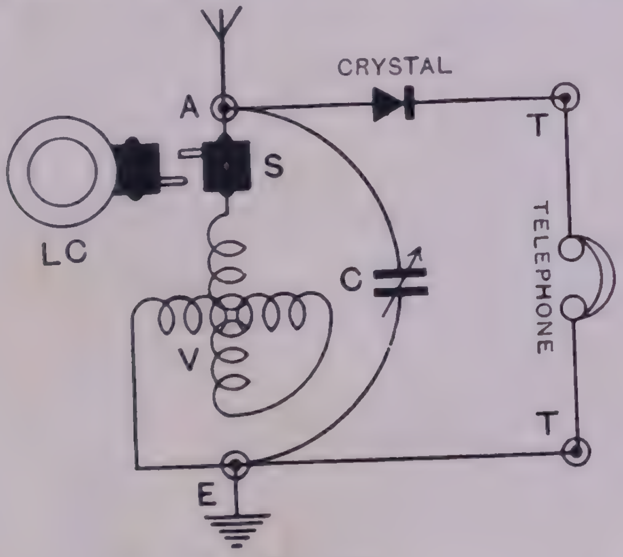


Fig. 144.

The outer tube or stator of the variometer $V$ is $4\frac{1}{2}$ inches long and 4 inches in diameter, and carries 36 turns of about 26 S.W.G. insulated copper wire (cotton covered) of about 26 S.W.G. The inner tube or rotor of the variometer is 2 inches long and 3 inches in diameter, and carries 28 turns of wire. The two windings are of course in series.

A "plug-in" socket (plug-in coil holder) $S$ is provided so that an additional plug-in coil $LC$, termed a **loading coil**, may be inserted to increase the inductance in the variometer circuit and enable the longer waves from Daventry to be received : a number 150 or 200 coil should be used for this purpose. When not receiving from the high power station the socket or holder $S$ must be short circuited by a short circuiting plug, the loading coil being removed.

Tuning is facilitated, particularly on the high wave length, if a variable condenser $C$ of ·0003 or ·0005 microfarad capacity be joined across the aerial and earth terminals $A$ and $E$ as shown. It should be remembered that *the more capacity we use in parallel with the inductance the longer the wave length to which the combination is tuned.*

Good telephones of 4,000 (or 8,000) ohms resistance, and a good type of detector should be used.

In tuning, all that is necessary is to rotate the variometer and vary the condenser until signals of maximum strength are obtained. This simple set has given satisfactory results at 6 miles from 5IT (Birmingham) and in Cambridge, 54 miles from 5XX (Daventry).

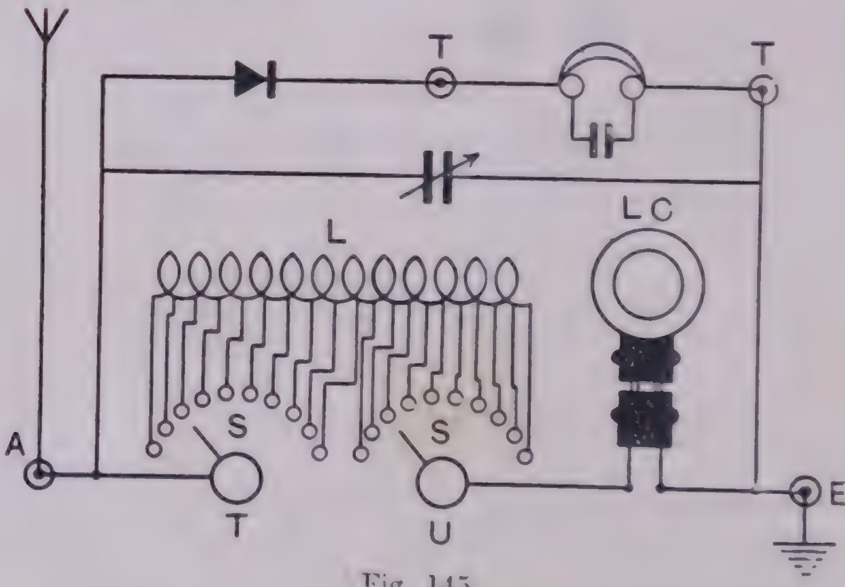
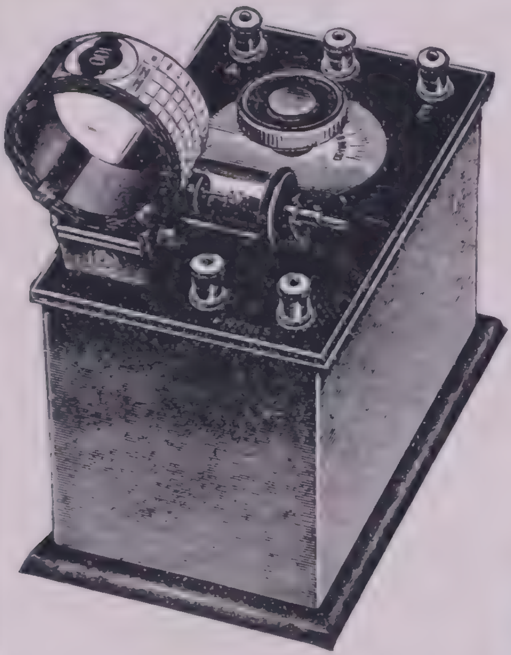


Fig. 145.

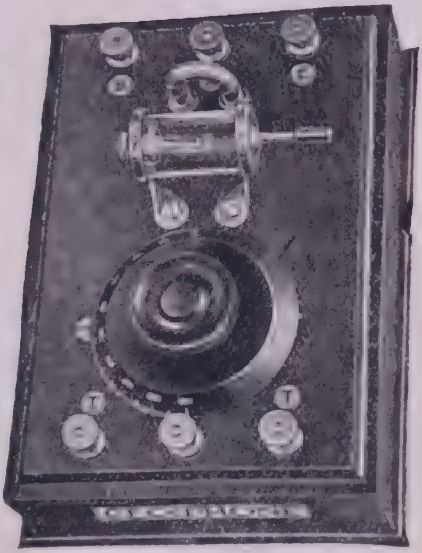
Fig. 145 shows the connections for a **tapped inductance crystal receiver.** The inductance $L$ is made of 100 turns of 24 gauge insulated (double cotton) copper wire wound on a cardboard tube 3 inches in diameter and 6 inches long, and, from different points of the coil, tappings are taken to the two sets of studs shown. Between one stud and the next in the $U$ set of studs one turn of wire is connected, whilst between each pair in the $T$ set of studs ten turns of wire are connected. Connection to different parts of the coil is made by means of the rotating switch arms $S$, $S$.

A small fixed condenser of about ·002 mfd. capacity joined

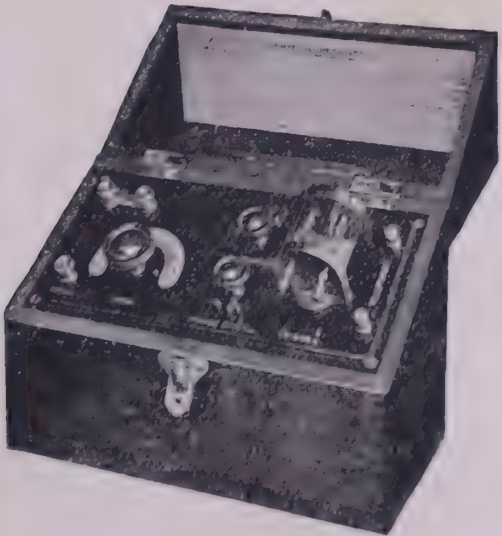
# TYPICAL CRYSTAL RECEIVING SETS.



(1) The Gōltone Crystal Receiving Set (Ward and Goldstone, Manchester).



(2) The Gecophone Crystal Receiving Set (General Electric Co., Birmingham).



(3) The B.T.H. Crystal Receiving Set (British Thomson-Houston Co., Rugby).

across the telephone terminals sometimes improves the reception, for it forms a by-pass for any *high frequency* pulsations of current: it also helps the audio frequency pulsations to pass through the telephones. The loading coil *LC*, as in the previous set, is to be used when receiving the longer Daventry waves: the coil must be removed and the holder short circuited when receiving on the ordinary broadcast band.

In tuning, the switch at *T* is placed on the first tens stud and the switch at *U* is slowly moved over the whole of the units studs. If no signals are heard *T* is placed on the second tens stud and *U* is again slowly moved over the whole of the units studs. This is repeated until signals of good strength are heard.

Still finer tuning may be obtained if a variable condenser be joined between the aerial and earth terminals as previously indicated. In this case tuning is first carried out as above, and then the condenser is varied.

This particular circuit has been used 6 miles from 5IT, 8 miles from 5NO (Newcastle), and 54 miles from 5XX with excellent results.

Fig. 146 gives the circuit for a **fixed coil crystal receiver**. The plug-in coil *L* must be of such a size (*i.e.* such an inductance) that it is suited to the particular wave length to be received. In parallel with the coil is a variable condenser $C_1$ by means of which tuning is effected.

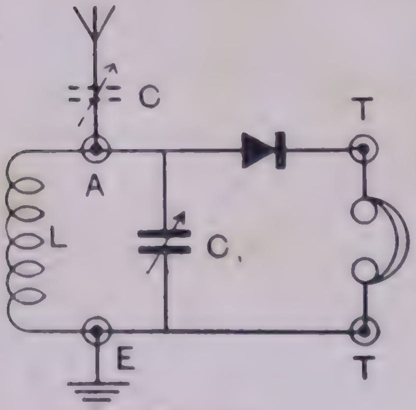


Fig. 146.

With a variable condenser of ·0005 microfarad capacity in parallel, a No. 35 or 50 coil will be suitable for broadcasting from the shorter wave stations and a No. 50 or 75 for the longer waves: for the Daventry high power station a No. 150 or 200 coil is suitable.

It may happen that reception is improved by placing the variable condenser *in series* with the coil as indicated at C. It should be remembered that *putting capacity in series with* *the inductance lowers the wave length range* (compare page 168). This will also be partly gathered from the following table, which gives the average wave length ranges for a number of different coils now on the market.

| Number of Coil. | Wave length range with ·001 microfarad condenser in parallel. | Wave length range with ·0005 microfarad condenser in series. |
|---|---|---|
| 25 | —400 | —350 |
| 50 | 200—700 | 200—550 |
| 75 | 250—1,000 | 250—800 |
| 100 | 300—1,500 | 300—1,000 |
| 150 | 400—2,500 | 400—2,000 |
| 200 | 600—3,000 | 600—2,500 |
| 250 | 800—4,000 | 800—3,000 |
| 300 | 1,000—5,000 | 1,000—3,500 |

Whether a series or a parallel arrangement is better in any particular case depends upon aerial conditions, etc., and must be settled by trying both. In a general way, for the longer waves, say 600 or 700 metres upwards, (lower frequency) a parallel arrangement is better because a series condenser increases the resistance in the tuning circuit (and lowers the amplitude) and although this may be inappreciable on the shorter waves, it begins to make itself felt on the longer waves. As stated, however, both should be tried.

The main drawback to this circuit is that tuning is inclined to be flat. Very good results, however, have been obtained with it at 6 miles from 5IT, and good results in Cambridge at 54 miles from 5XX. At Cambridge interference from ships was more pronounced with this circuit than with the two preceding circuits.

**112. Modern Tendencies in Crystal Circuits.**—A crystal of course always absorbs energy from the circuit, and must cause damping. Theoretically the detector and telephone circuit should have such a large resistance that it produces no appreciable effect on the tuned circuit (inductance and condenser) across which it is joined. In a crystal circuit, although the resistance is comparatively high, it is not high enough to fulfil the condition stated, and in consequence we have damping and flat tuning and selectivity suffers.

Now it can be shown that if this damping can be varied and made of the same order as that due to other resistances in the circuit the signal strength and selectivity will be increased. Fig. 146*a* shows a circuit with this object in view: it is modified from that of Fig. 146 in the sense that the crystal is tapped across part of the inductance only, and by varying this tapping it is clear that the damping in this circuit can be varied until the best condition is found.

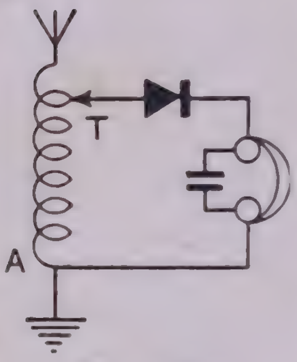


Fig. 146*a*.

If this tapping point *T* be quite close to *A* the portion of the voltage across the inductance which is available for the crystal and telephones is quite small, with the result that the signals are weak. As the tapping point is raised the signals become stronger, until a point is reached where the signals are a maximum. If the tapping point be still further raised the signal strength falls off owing to the damping. Fig. 147 gives the general shape of the curve, showing the relation between the tapping point and the signal strength. Tuning consists in finding the tapping point which gives the peak of the curve.

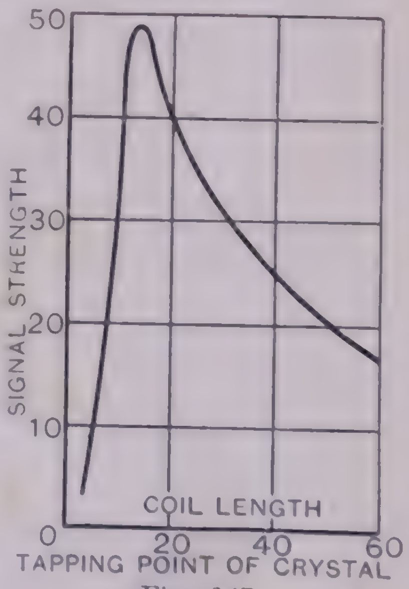


Fig. 147.

An **auto-coupled aerial circuit** as it is called, *i.e.* an aerial tapped across part of the inductance, may be combined with a crystal tapping as indicated in Fig. 148, which is self-explanatory.

Again, interference is often experienced from ships in the case of an ordinary crystal set used near the coast, and one reason for this is that the detecting part is straight across the aerial inductance, etc., the one and only tuned circuit to fight against the interfering ships. Hence modern crystal circuits often utilise the property of induction between a primary coil in the aerial circuit and a secondary coil in the crystal and telephone circuit. The aerial circuit is tuned by either tappings or a condenser to the arriving waves, and to improve matters the secondary or crystal circuit is also frequently tuned to the primary circuit.

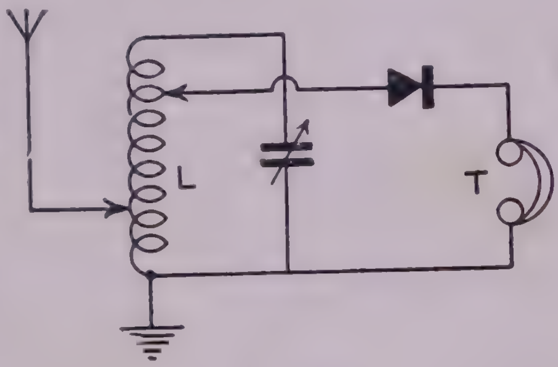


Fig. 148.

In such a case the crystal circuit, being separate from the aerial circuit, has not got the damping of this latter circuit connected with it, and in consequence its tuning is sharp and interference is reduced. Fig. 149 shows diagrammatically the arrangement : the tuning condenser in the aerial circuit may be either in series or in parallel. Further, *P* and *S* may be fixed, or the distance apart, *i.e.* the coupling, may be variable : this latter is the true "loose coupled" form.

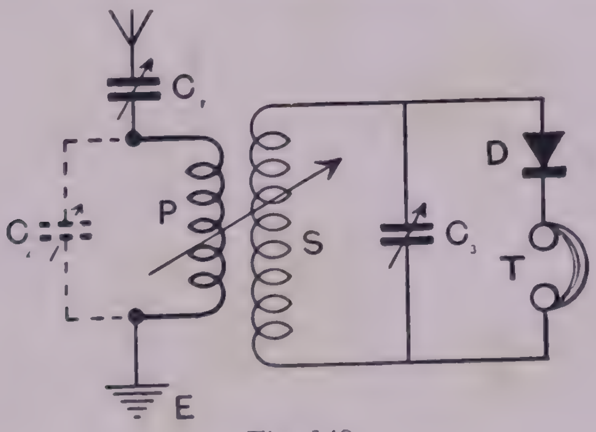


Fig. 149.

Fig. 150 gives a **fixed coupled circuit** in detail. The secondary coil *S* is fixed inside the primary coil *P*, but for clearness they are shown apart. *P* consists of about 40 turns of wire of 22-24 gauge wound on a cardboard tube about 3½ inches in diameter and 4 inches long. One end of the wire and tappings of three turns each are taken to the studs as indicated. *S* consists of 90 turns of wire of 30-32 gauge wound on a cardboard tube 3 inches in diameter. A variable condenser may be joined across the secondary circuit, thus giving two tuned circuits.

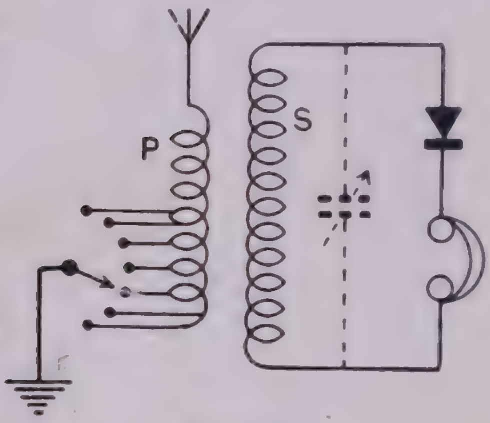


Fig. 150.

Fig. 151 depicts a modification in one form of what we have called a **loose coupled circuit**. The two coils *P* and *S* are mounted in a two-coil holder, *P* being fixed and *S* movable, so that its distance from *P* can be varied. The variable condenser $C_1$ has a capacity of ·0005 microfarad. $C_2$ is the usual fixed condenser of about ·001 or ·002 microfarad.

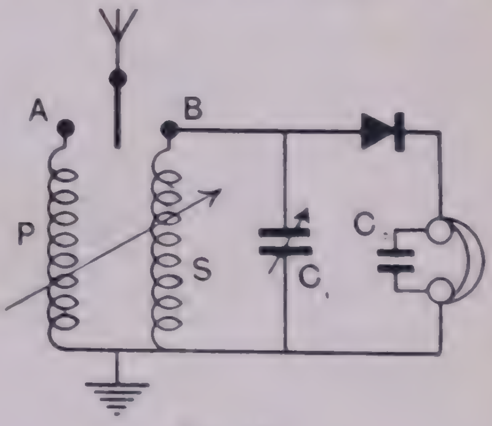


Fig. 151.

With the switch on stud *A* the circuit is a coupled one. In this case, for the broadcast band of waves, *P* may be a No. 35 or 50 coil and *S* a 75: for the Daventry longer waves *P* may be a No. 150 or 200 and *S* a No. 200 or 250 accordingly. Tuning is accomplished by varying the distance between *P* and *S* and adjusting the condenser $C_1$. Smaller values of *P* should also be tried.

If the switch be turned to the stud *B* the coil *P* is cut out and we get the fixed coil circuit of Fig. 146. In this case for ordinary stations *S* may be a No. 35 or 50 coil, and for Daventry a No. 150 or 200 coil.

The first arrangement is referred to as **loose coupled semi-aperiodic aerial tuning** : in it we have a fixed untuned coil in the aerial circuit, loose coupled to a tuned coil in the crystal circuit, its tuning being done by $C_1$. This circuit is very selective and is specially suited to those who experience interference, particularly from ships.

**113. Increasing the Signal Strength of a Crystal Receiver.**—One of the first aims of the experimenter or even the " listener in " on the crystal receiver is to increase the strength of the signals he is receiving from the local station or Daventry, *i.e.* to obtain a greater volume of sound in the telephones ; invariably he is more interested in this than in any attempt to increase the range and bring in more distant stations.

Now one of the best methods of securing this object is to add a valve to the crystal receiver in such a way that the rectified signals from the crystal (which in the ordinary crystal receiver would go direct through the telephones) are magnified or amplified by the valve and then passed through the telephones, with the result that a much louder sound is heard. A valve used in this way is referred to as a **low frequency** or **audio frequency amplifier**, or a **note amplifier**.

Such a valve may also be said to increase the effective range of the crystal set. Thus suppose a crystal receiver gives really good reception at 10 miles from a station, but at 20 miles from the station the signals, although they can be heard, are very weak. On the addition of the low frequency amplifying valve these weak signals may be sufficiently magnified to become distinctly audible, and in this sense the valve has increased the range. At the same time the main object of the valve used in the sense indicated is to increase signal strength.

The necessary connections are shown in Fig. 152. The telephone terminals *T*,*T*, of the crystal set are connected to the terminals of the primary coil *P* of a low frequency transformer (it does not matter " which way round " these wires are joined to the primary) of which many excellent types are on the market. One terminal of the secondary coil *S* of the transformer is joined to the grid terminal of a valve holder. The plate terminal of the valve holder is joined to one telephone terminal, the other telephone terminal being joined to the positive pole of the high tension battery *HT*—usually a dry battery of about 70-80 volts. From the negative terminal of this battery a wire goes to the positive pole of the low tension battery *LT*—usually an accumulator battery, the voltage of which will depend on the type of valve employed—and a wire is also taken from this positive pole to one of the filament sockets of the valve holder. From the negative terminal of the low tension battery a wire goes to the second terminal of the secondary coil *S* of the transformer, and another wire goes from this negative terminal to one end of the filament rheostat *R*, the other connecting point of which is joined to the remaining filament socket of the valve holder.

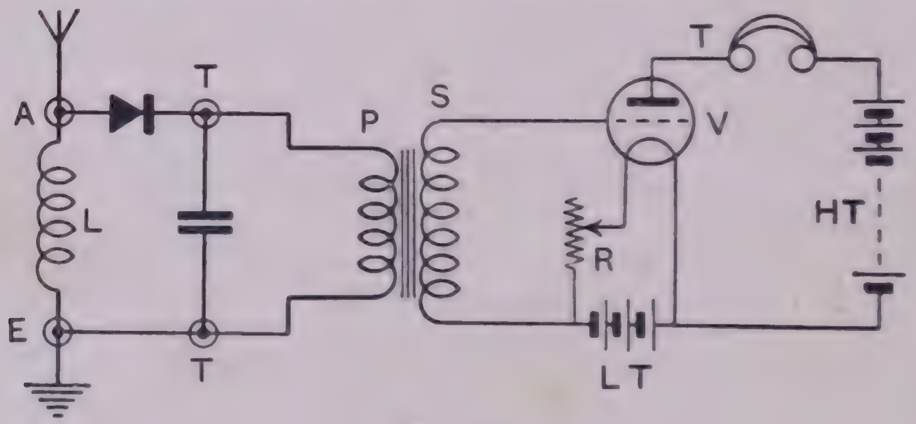


Fig. 152.

The valve used may be any type of what is called a *general purpose valve* or any specific make of *low frequency valve* (but *not* a high frequency valve) : cheap soft Dutch and French valves should be avoided—" British Goods are Best." Whatever type of valve is used, however, the makers' instructions with regard to the required voltage for the L.T. battery, the filament current, the best H.T. voltage, etc. must be attended to.

A suitable value for the ratio of the transformer windings in this case is 4 or 5 to 1. The primary terminals are generally marked I.P. and O.P. and the secondary terminals I.S. and O.S. : the O.S. terminal should be joined to the grid of the valve.

In tuning, the filament rheostat is turned until the filament is at the correct brightness, and the crystal is adjusted until the signals are at a maximum : these signals will be from four to six times as strong as with the crystal alone, and three or four telephones or more can be used in series. Sometimes the arrangement is sufficient to work a small loud speaker.

If the student wishes to go a step further and efficiently work a loud speaker on the local station, a second stage of low frequency amplification may be used by means of a second valve ; thus the receiving set will consist of a crystal detector followed by two low frequency amplifying valves. Most students, however, will at this stage probably prefer circuits in which valves only are used : in any case the method of arranging two low frequency amplifiers in connection with a valve detecting circuit is given in Chapter XII., and the general principles are the same if a crystal is used as detector.

**114. Increasing the Range of a Crystal Receiver.**—If it is desired to increase the range of a crystal set so as to bring in the more distant stations, what is known as a **high frequency amplifying valve** must be employed. In this case a valve is used in front, so to speak, of the detector, so that it takes the weak signals just as they are produced in the aerial (high frequency) and magnifies them, and then passes these magnified signals on to the crystal set for rectification and detection. Fig. 153 gives the circuit in question.

In this figure the aerial circuit consists say of a fixed coil $L$, and a variable condenser $C_1$ in parallel, the same so far as Fig. 146. For the ordinary broadcast band $L$ may be a No. 35 or 50, and $C_1$ of ·0005 microfarad capacity. This tuned circuit is connected between the grid and filament of the valve as indicated. From the plate of the valve a wire goes to the aerial terminal of the crystal receiver, whilst from the earth terminal of the crystal receiver a wire goes to the positive pole of the high tension battery HT. Other connections will be readily understood from the figure, in which $LT$ is the low tension battery.

The crystal circuit between the $A$ and $E$ terminals must be a tuned circuit consisting say of a plug-in coil and variable condenser in parallel as in Fig. 146. If the simpler type of crystal set is being used—say a simple variometer or variable coil set—it may be necessary to insert a condenser as indicated at $C$ by the dotted lines: a small fixed condenser of about ·0003 microfarad will answer the purpose.

It will be noted that the tuner—coil and parallel condenser—of the crystal set is in the anode circuit of the valve, and the arrangement is referred to as a **tuned anode** arrangement or coupling between the amplifier (valve) and the detector (crystal).

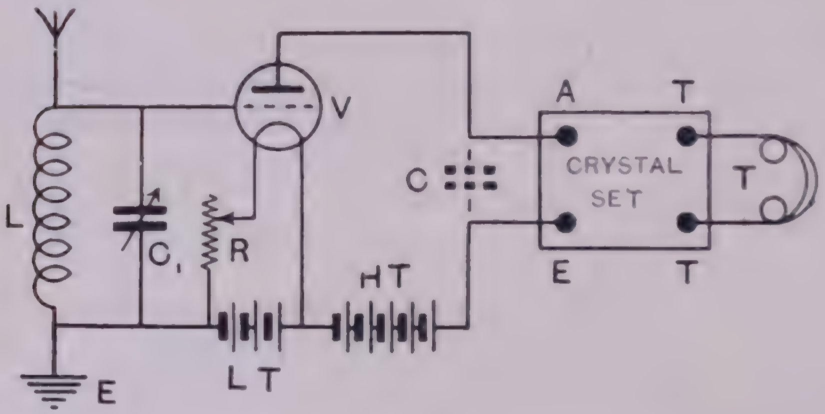


Fig. 153.

The valve used may be a *general purpose* or a special *high frequency valve*, and the makers' instructions must, as in the preceding case, be attended to. The H.T. voltage in this case is frequently less than in the preceding—say about 60 volts.

Two circuits are to be tuned, viz. the $LC_1$ circuit by means of $C_1$, and the crystal tuner.

**115. Increasing the Signal Strength and the Range of a Crystal Receiver.**—The two preceding cases may be combined so as to form a set consisting of one stage of high frequency amplification (valve) followed by a rectifier or detector (crystal), this being again followed by a stage of low frequency amplification (valve). In this case the first valve magnifies the incoming high frequency signals: these are passed on to the crystal to be rectified: these rectified signals are passed on to the second valve which further amplifies at low frequency: finally the signals are heard in the telephones. Such a circuit in its simplest form is shown in Fig. 154: in its performance it is practically as good as an ordinary three valve set without reaction (see Chapter XII.).

There are many ways in which the connections for this circuit can be made, but the circuit shown in Fig. 154 is given at this stage for simplicity, for a careful examination of this figure will show that it is merely a combination of the two preceding circuits. The coils $L_1$ and $L_2$ are plug-in coils, suitable values being, for $L_1$ 35 or 50, and for $L_2$ 60 or 75, if reception is required from ordinary stations. For Daventry a No. 150 for $L_1$ and 250 for $L_2$ will be suitable. The variable condenser $C_1$ may be ·0005 microfarad and $C_2$ ·0003 microfarad. It will be noted that the circuit embodies tuned anode coupling on the left and transformer coupling on the right.

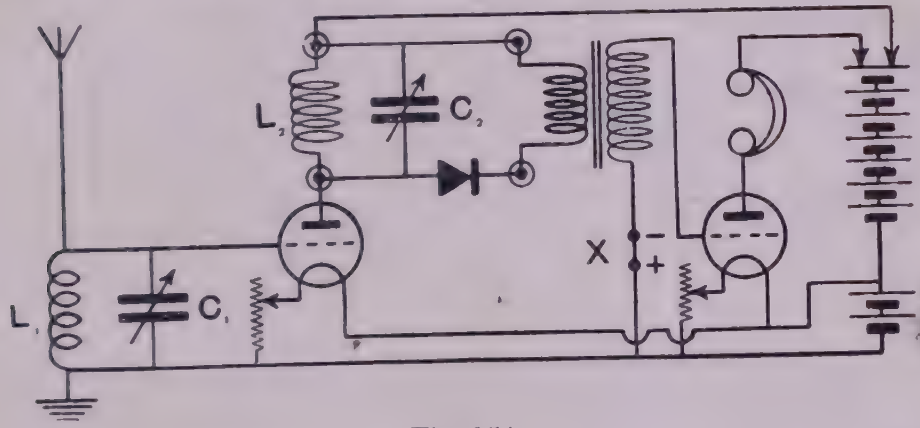


Fig. 154.

Matters are sometimes improved if a little *negative bias* be given to the grid of the second valve (see Chapter XII.). This can be done by inserting a small dry battery, known as a grid bias battery, at the point $X$, its *negative* pole being joined to the secondary of the transformer.

**116. Increasing the Signal Strength of a Crystal Receiver without the Use of Valves.**—Many attempts have been made to increase the signal strength of crystal receivers without the use of valves, and in recent years these attempts have met with a certain amount of success, but the valve method previously described, and others somewhat similar, are at present undoubtedly the best.

Incidentally it may be mentioned that if the incoming signals, *i.e.* the signals applied to a crystal, be increased beyond a certain point, the crystal begins to conduct in both directions, and its efficiency as a rectifier falls off. High frequency amplification in any form, therefore, has its limitations, and beyond this point any further improvements must be made on the other side, *i.e.* at audio or low frequency.

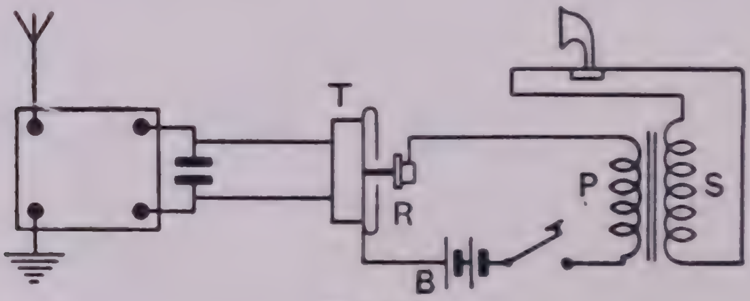


Fig. 155.

A method of amplification without valves, due to Mr. I. Skinderviken, is as follows :—The telephone terminals of the crystal set are joined to a single telephone ear-piece *T* (Fig. 155). Attached to the diaphragm of the ear-piece by means of a light rod is one electrode of a small relay *R*. Between the two electrodes of the relay are carbon granules. The circuit of the relay is completed through a battery *B* of 4 dry cells and the primary coil *P* of a transformer, the secondary coil *S* of which is joined to the telephones or loud speaker.

Clearly the vibration of the diaphragm of the telephone ear-piece due to the signals received is transferred to the relay, producing compressions and decompressions of the carbon granules, and thus varying the resistance in the battery circuit. This results in corresponding variations in the current from the battery, which variations are magnified by the transformer, and the loud speaker responds, giving out signals the same as are received by the telephone ear-piece, but considerably magnified.

This apparatus has been experimented on and fully described by Mr. B. E. Jones, the Editor of *Amateur Wireless*, from whom full particulars of the apparatus may be obtained. It is claimed that with a crystal set which normally gives good results, a loud speaker can be worked with sufficient volume to fill a large room. Music is said to be good, but speech, although quite understandable, a little gramaphonic.

A somewhat similar device known as the "microphone bar" has recently been put on the market. The bar clamps to a telephone ear-piece in the usual telephone circuit of the crystal set, and includes in its circuit a transformer, two dry cells, and the receiving telephones or loud speaker after the manner of Fig. 155. It is claimed that signal strength is increased from three to ten times without distortion. The device is manufactured by the New Wilson Electrical Manufacturing Company of London.

**117. Further Points for Crystal Users.**—In addition to the many points mentioned in the preceding chapter, the following should be noted :—

(*a*) Coil sizes have been given in connection with the various circuits described; for general guidance it may be again mentioned that about 100 turns of 24 S.W.G. copper wire (double cotton covered) wound on a tube about 3 inches in diameter (with tappings or other means of adjustment) is suitable for broadcast reception.

(*b*) The question of a series or parallel tuning condenser is best settled by trial; frequently for wave lengths below about 700 metres a series condenser comes out the better of the two, whilst for waves above this length the parallel condenser is better, as already explained. The series condenser should be connected between aerial and inductance rather than between inductance and earth. Further, it is always better to join the moving plates of a condenser towards the earth side of the apparatus rather than to the aerial side.

(*c*) A crystal should not be heated, or exposed to air or dust, or touched with the fingers, and all parts should be insulated from earth.

(*d*) It is not advisable to clean(?) crystals with petrol (as is sometimes recommended), or to hack them about with a penknife : it is cheaper to buy a new crystal than a new penknife.

(*e*) It is a mistake to force a catwhisker tight up against a crystal : a light gentle touch is all that is needed. It is equally a mistake to poke about with a catwhisker and a crystal in the gloaming or in the dark : it may lead to anything, except to a sensitive spot on the crystal.

TYPICAL VALVE-CRYSTAL SET.

B.T.H.

Finally, even the multi-valver or the advocate of the "super" circuit should not despise the humble crystal. After all it is a better rectifier than a valve and its results are purer. It is well worthy of further experimental investigation.

# CHAPTER XI.

## SINGLE VALVE RECEIVING SETS.

**118. Introduction.**—Almost every crystal user turns his attention, sooner or later, to valves, in the desire for reception from more distant stations, louder signals, and greater selectivity, and naturally the one valve receiving set first attracts his attention. Moreover, the single valve receiver is very popular partly because *within its limits* it is a satisfactory instrument for the " listening in " members of the household, and partly because it opens up a wide range of experiments for those so inclined.

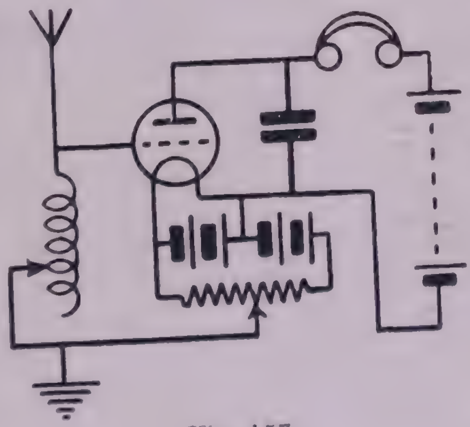


Fig. 157.

Many varieties of circuit arrangements have been evolved for the use of a single valve, and some essential points in connection with a few of these will be dealt with in this chapter. Before proceeding further, however, the student should carefully examine Figs. 157, 158 so as to get again a general idea of the connections of a valve circuit to the aerial inductance. In Fig. 157 the contact on the potentiometer joined across the battery in the lower part of the figure is adjusted so that the steady grid potential falls at either of the two " knees " of the characteristic curve of Fig. 120, and the first method of using the valve as a rectifier dealt with in Art. 100 is employed : in Fig. 158 the more usual grid condenser and grid leak method of using the valve as a rectifier—the second method dealt with in Art. 100—is employed. It will be noted that in both cases the oscillatory potential differences set up in the aerial inductance by the arriving waves are applied between the grid and filament of the valve, thereby producing changes in the plate current which in turn operate the telephone in the plate circuit in the manner dealt with in preceding chapters.

The above simple straight circuits are rarely used, however, for in most cases some form of what is called **reaction** or **retro-action** or **back coupling** is employed, thereby (amongst other things) increasing signal strength, whilst special arrangements are introduced to eliminate interference and improve selectivity.

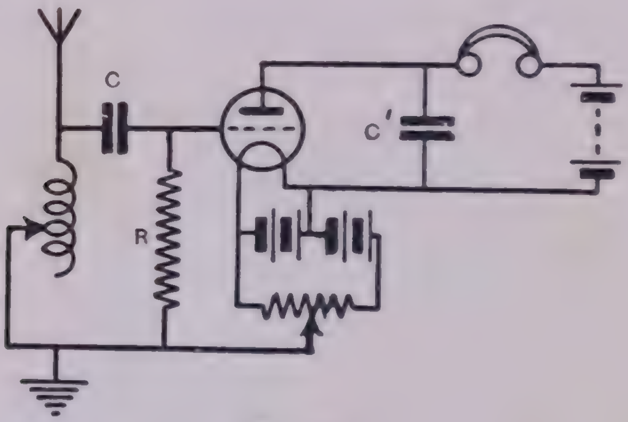


Fig. 158.

### 119. Reaction, Retro-action, or Back Coupling.

**119. Reaction, Retro-action, or Back Coupling.**—As already indicated, the oscillatory potential differences set up in the aerial by the arriving waves are applied between the grid and filament of the valve, as is clearly seen from the preceding figures. Now some of this received energy in the grid circuit is dissipated or wasted in the resistance of the grid circuit and, of course, the amount of incoming energy actually available for the valve to work with is reduced. Clearly then, if this dissipated energy can be made good by adding energy in some way to the grid circuit from some other source, the voltage variations between the grid and filament will be greater, the corresponding changes in the plate current will be greater, and signal strength will therefore be increased. This is accomplished by the arrangement shown in Fig. 159, and is known as *reaction*, *retro-action*, or *back coupling*.

In the figure $L_2$ is an inductance, called the **reaction coil**, in the plate circuit of the valve: it is coupled to the inductance $L_1$ in the aerial and grid circuit, the distance between the two coils being usually variable: this variable coupling is obtained by mounting $L_1$ and $L_2$ in a two-coil holder such as was depicted in Fig. 67. The varying current in the $L_2$ and plate circuit (which current is, of course, being drawn from the high tension battery) acts inductively on $L_1$, thus adding energy to the $L_1$ and grid circuit, and by suitable arrangement of the value of the reaction coil $L_2$ and the distance between $L_1$ and $L_2$, *i.e.* the coupling, this energy can be made to help that in the grid circuit, and to compensate for the energy dissipated in this circuit: in other words, energy is being fed back from the plate circuit to the grid circuit, to make up the loss there. The result is, as previously stated, greater variation in grid potential, greater resulting variation, therefore, in plate current, and hence greater signal strength.

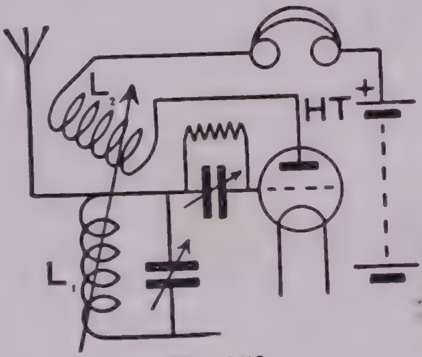


Fig. 159.

The connections of the reaction coil must, of course, be such that the energy fed back assists that already in the grid circuit—the two must, as it were, be in step. If signal strength be weakened when the reaction coil is brought nearer the other coil it is a sign that it is connected the wrong way round, and the connections must be reversed.

It looks at first as if signal strength could be increased in this way indefinitely, but there is a limit. If more than a certain amount of energy be fed back into the aerial and grid circuit the set breaks into self-oscillation and begins to radiate. Music and speech become distorted, howls and squeaks result from the "heterodyning" (Art. 93) of the carrier wave, and the operator joins the ranks of the "oscillating fiend"—that unmitigated nuisance to all listeners in the vicinity.

The object to be aimed at in tuning is to get the reaction coil as close to the other as possible without actually falling into self-oscillation, but the operator should turn it away immediately on the first sign of oscillation. Experience will soon teach when this stage is approaching. On getting near the oscillation condition there is usually a rustling sound or a click in the telephones, signals begin to be distorted, and if the tuning condenser be slightly varied, some whistling and howling will occur. Another test for oscillation is to notice if a loud click occurs in the telephones when the aerial terminal is touched with the finger. Beginners are inclined to be in far too great a hurry when tuning in.

If a set goes into oscillation with a loud click, and continues to oscillate when the reaction coil is moved back even beyond the position where oscillation began, it is possible that the high tension battery voltage is too high or the filament current too low. Too large a reaction coil should also be avoided: for a single valve set on the ordinary broadcasting band of waves a No. 75 should rarely be exceeded. Students making their own reaction coils will find that in a general way about 70 turns of No. 28 gauge wire wound in a coil $1\frac{3}{4}$ inches in diameter will be suitable for the broadcast band.

Another method of obtaining reaction is to join a small variable condenser between the plate of the valve and the side of the coil which is connected to the grid: a little consideration will show that the explanation of the action is somewhat similar to the preceding.

Reaction, suitably arranged, increases selectivity as well as signal strength. Since it compensates for the energy dissipated in the resistance of the grid circuit it is, as it were, equivalent to the reduction of the effective resistance: thus we have a "low loss" circuit, and, as already indicated, this results in sharp tuning.

Incidentally, it may be mentioned that in every receiving set there is a certain amount of inherent reaction due to capacity and induction between various parts. This stray coupling, if excessive, may cause a set to oscillate without the assistance of a reaction coil, and may be a source of trouble. To avoid it as much as possible care must be taken in arranging the various components in a receiver, especially the relative positions of wires, etc. on the input (grid) and output (plate) sides of the valve. If a circuit oscillates without assistance as a result of this stray coupling a reaction coil may be so connected that it feeds back energy in such a way as to oppose that already there : this is done by connecting the reaction coil in the opposite direction to that in which it would be normally connected. Specially arranged circuits have also been designed to neutralise this stray coupling, or to make it less pronounced. *e.g.* neutrodyne receivers, Armstrong super-regenerative receivers, etc. (see later).

**120. Single Valve Circuit with Reaction.**—A simple single valve circuit with reaction is shown in Fig. 160. The aerial inductance $L_1$ and the reaction coil $L_2$ are of the plug-in type and are fixed in a two-coil holder (Fig. 67), the coil $L_2$ being the movable coil. The aerial tuning variable condenser $C_1$ is of capacity $\cdot 0005 \mu F$, the fixed grid condenser $C_2$ is of capacity $\cdot 0003 \mu F$, whilst the telephone condenser $C_3$ is a fixed condenser of about $\cdot 002 \mu F$ capacity. The grid leak $R$ is one of 2 megohms resistance. Incidentally, in most of the valve circuits given in this book the H.T. negative pole is joined to the L.T. positive pole, and the filament resistance is in the lead joined to the negative pole of the L.T. battery.

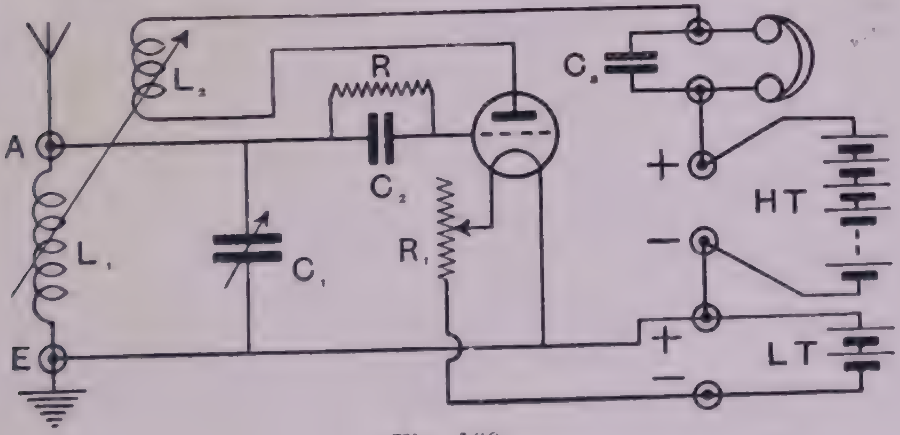


Fig. 160.

The size of the coil $L_1$ depends, of course, on aerial conditions, and should be as small as possible consistent with good signals. If too small selectivity will be good, but signal strength poor : if too large both selectivity and signal strength will be poor. For the lower broadcasting band $L_1$ may be a No. 35 coil and $L_2$ a No. 50, while for the higher broadcasting band $L_1$ may be a No. 50 and $L_2$ a No. 75. For the long wave stations, $L_1$ may be a No. 150 or 200 and $L_2$ a No 200 or 250.

Any general purpose or detector valve may be employed, the necessary filament voltage and high tension voltage depending on the type of valve used (indicated by the valve makers). The filament resistance $R_1$ is about 10 ohms for bright emitter valves and 30 ohms for dull emitters taking ·06 ampere.

The telephones are inserted in the plate circuit as indicated : if the telephone terminals are marked + and — (and all should be), the + terminal should be joined to the positive pole of the battery, so that the current will not go through the telephones in the wrong direction, thus weakening their magnetism.

In tuning in to any particular station. the reaction coil must be well back from the aerial coil and $C_1$ must be adjusted until the best signals are obtained. The reaction coil must then be brought gradually up towards $L_1$ for increased signal strength, $C_1$ being further slightly adjusted during the process. The movement of $L_2$ must be stopped at a point below that at which the set breaks into oscillation.

**121. Experimental Modifications in the Preceding Single Valve Circuit.**—Many students are of an experimental turn of mind, and are anxious to " try out " new circuits. but hesitate to do so in their early wireless days, partly because they fear the new circuit may be no improvement on what they already have, and partly because of the annoyance to the non-experimental members of the household if the set is disconnected and out of action for a short period (which they will certainly describe as " a considerable time "). The following modifications, none of which will put the set out of action for more than a few minutes are therefore suggested as possible improvements.

(*a*) In place of the fixed condenser across the telephone terminals try a variable one of $\cdot 002 \mu F$ maximum capacity. First set this a little below its half scale reading and then tune in as previously indicated. When this is done it will probably be found that a further adjustment of this telephone condenser will enable the reaction coil to be brought nearer to the oscillation point without that point being overstepped.

(*b*) Join a variable condenser $C_4$ of $\cdot 0005 \mu F$ capacity across the reaction coil as indicated in Fig. 161. Set this at a little below half scale and then tune in as before, finally using $C_4$ as a control as in (*a*).

(*c*) Put the preceding variable condenser between the end of the reaction coil which is joined to the plate of the valve and the positive pole of the low tension battery as shown in Fig. 162 (the *moving plates* of the condenser should be joined to the battery). Begin with $C_4$ near the lowest scale reading and tune in as before. Then increase $C_4$ slowly and reduce $C_1$ slowly, and adjust $L_2$ slowly; results will be as in (*a*).

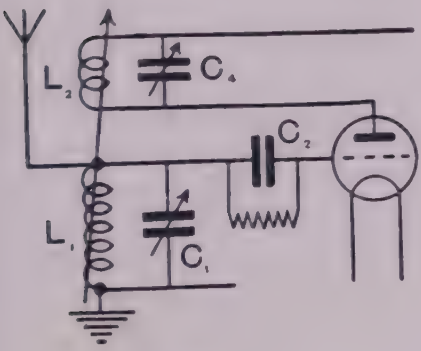


Fig. 161.

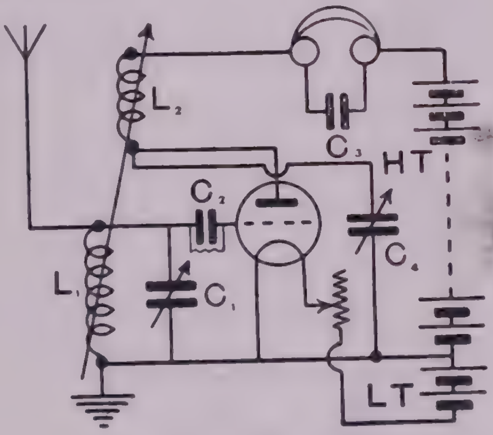


Fig. 162.

**122. Loose Coupled Single Valve Circuit.**—Before proceeding far in his valve experiments the student will realise more and more the importance of selectivity, and the necessity of being able to cut out unwanted signals or the local broadcasting station when wishing to receive a distant station. As already indicated in Chapter X., greater selectivity is obtained if, instead of a direct coupled aerial as in Fig. 160, an auto-coupled aerial be employed, as shown in Figs. 145, 148. The particulars there given are also suitable for use with a valve circuit. Another method of improving selectivity, also indicated in Chapter X., is to employ loose coupling between the aerial circuit and a closed secondary circuit.

Fig. 163 depicts a single valve circuit employing loose coupling. In this circuit a three-coil holder (Fig. 164) is employed to carry the three plug-in coils $L_1$, $L_2$, $L_3$. The reaction coil $L_3$ may be inductively coupled to the aerial coil $L_1$ as in Art. 120, or to the secondary coil $L_2$ in the closed circuit. In this valve circuit it is coupled to the secondary coil $L_2$, so that $L_2$ is placed in the central fixed coil carrier of the holder, and $L_1$ and $L_3$ in the movable coil carriers at each side of the holder. Thus the distance between $L_1$ and $L_2$ can be varied, and the distance between $L_3$ and $L_2$ can also be varied.

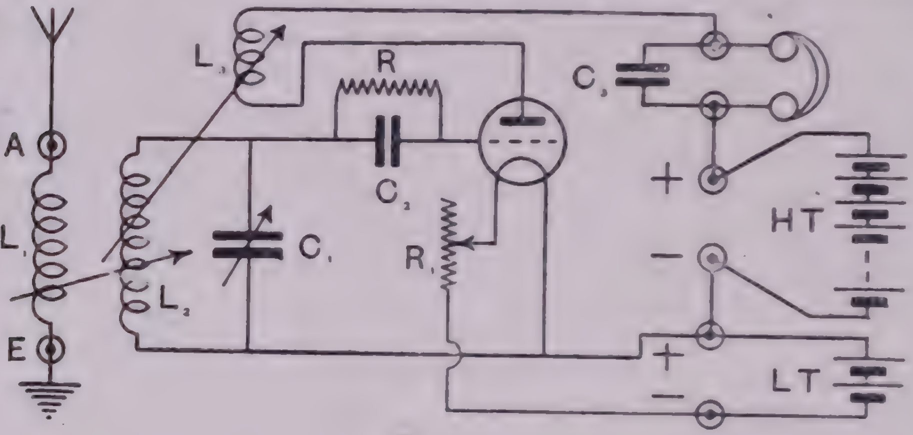


Fig. 163.

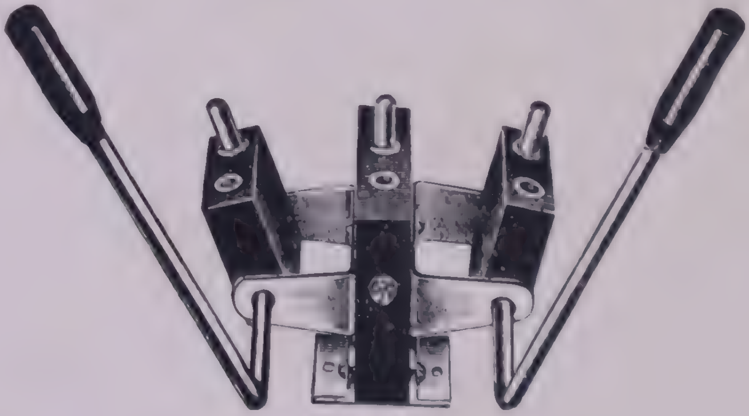


Fig. 164.

It will be noted that the circuit uses simply a coil (no tuning condenser) in the aerial circuit, inductively coupled to a tuned secondary circuit, the tuning being done by the condenser $C_1$; hence this is referred to as loose-coupled semi-aperiodic aerial tuning. The remaining part of the circuit is identical with that of Fig. 160.

For the broadcasting band of wave lengths, $L_1$ may be a No. 35 or 50 coil, whilst for the Daventry long waves a No. 150 coil will be suitable in most cases. For the broadcasting band $L_2$ may be a No. 50 or 75 coil, and the reaction coil $L_3$ a No. 75. For Daventry $L_2$ may be a No. 200 coil and $L_3$ a No. 200. Knowing the general coil values as above, different coils should be tried and the best decided upon by experiment.

In tuning, the reaction coil is set at right angles to the coil $L_2$, and $L_1$ at a good angle with $L_2$, and $C_1$ is adjusted. If no signals are heard, $L_1$ is brought a little nearer to $L_2$, and $C_1$ again adjusted, and so on until the best signals are obtained. Then $L_3$ is brought gradually nearer to $L_2$, further slight adjustments of $C_1$ being made as necessary until the desired maximum results are obtained.

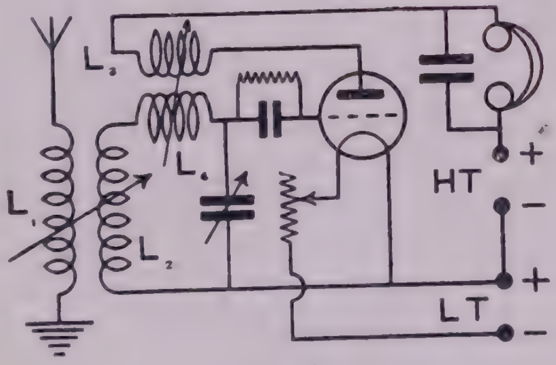


Fig. 165.

**123. Loose Coupled Single Valve Circuit with Split Secondary Reaction.**—A modification of the preceding, known as the **divided or split secondary reaction control** gives a decided improvement both in selectivity and in the control of the reaction. In this circuit (Fig. 165) the inductance in the secondary consists of two coils $L_2$ and $L_4$, arranged in the receiving set at right angles to each other so that the coupling between them is a minimum. The aerial coil $L_1$ is inductively coupled with one of these, $L_2$, and the reaction coil $L_3$ is inductively coupled with the other, $L_4$. For the broadcasting band a No. 50 coil for $L_2$ and a No. 35 coil for $L_4$ will be suitable. Two two-coil holders are necessary, one to carry $L_1$ and $L_2$ and the other to carry $L_3$ and $L_4$. The circuit diagram shown in Fig. 165 is self-explanatory.

The student should note particularly the three methods of using reaction shown in Figs. 160, 163, 165. In Fig. 160 the reaction coil is coupled to the aerial coil: in Fig. 163 it is coupled to a coil in the closed secondary circuit which is also coupled to the aerial coil : in Fig. 165 it is coupled to another coil in the closed secondary circuit which is not inductively coupled with the aerial. The latter two methods are superior to the first ; moreover they reduce the possibility of "oscillation interference" with other patient listeners-in in the vicinity.

**124. Reinartz Single Valve Circuit.**—Although originally intended for short wave reception this circuit can be adapted for the broadcast band of wave lengths. A point in favour of the **Reinartz circuit** is that in applying reaction practically no change takes place in wave length, and therefore in aerial tuning, and moreover reaction control is smooth and easy : this reaction control is finally done by a variable condenser. A Reinartz circuit is shown in Fig. 166.

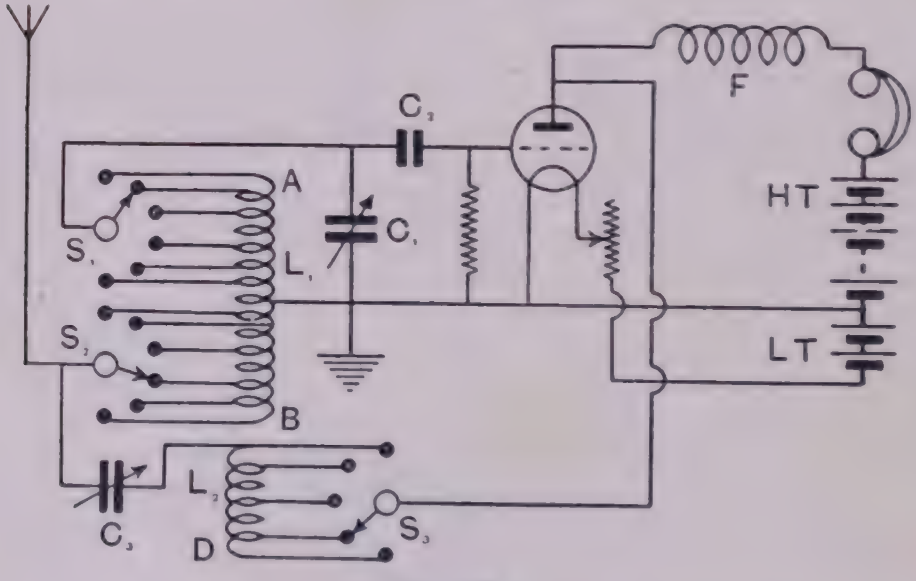


Fig. 166.

The coil *AB* consists of 45 turns of No. 22 double cotton covered copper wire wound on a vulcanite tube 3 inches in diameter. At the end *A* tappings are taken at 5, 5, 7, 9, and 10 turns and brought to the studs shown : then tappings are taken at 1, 1, 1, 2, 2, and 2 turns and joined to the studs shown at the end *B*. Another 45 turns of the same wire are wound on the tube (quite separate from *AB*), tappings being taken at 5, 10, 15, and 15 turns and joined to the studs at *D*. This latter coil is the reaction coil $L_2$.

The coil *F* is a choke coil consisting of about 100 turns of No. 26 silk covered wire wound on a tube 3 inches in diameter. It is inserted where indicated in order to choke back any high frequency currents from the telephones and compel them to pass along the path to *D*.

The tuning condenser $C_1$ is a variable one of $\cdot 0005\mu F$ capacity as usual, and the grid condenser $C_2$ is $\cdot 0003\mu F$. It will be noted that the reaction coil $L_2$ is not a swinging coil as in the previous circuits, but is fixed relative to *AB* : the reaction is roughly varied by means of the switch $S_3$, and then lastly a fine adjustment is obtained by means of a reaction condenser $C_3$ in the circuit of $L_2$. The reaction condenser (variable) is of $\cdot 0005\mu F$ capacity.

In tuning in, $S_1$, $S_2$, and $C_1$ are first adjusted in the usual way until a good signal is heard, then the reaction coil $L_2$ is varied by means of $S_3$, and finally $C_3$ is adjusted.

The circuit is very sensitive, and needs that careful methodical handling which only comes with practice.

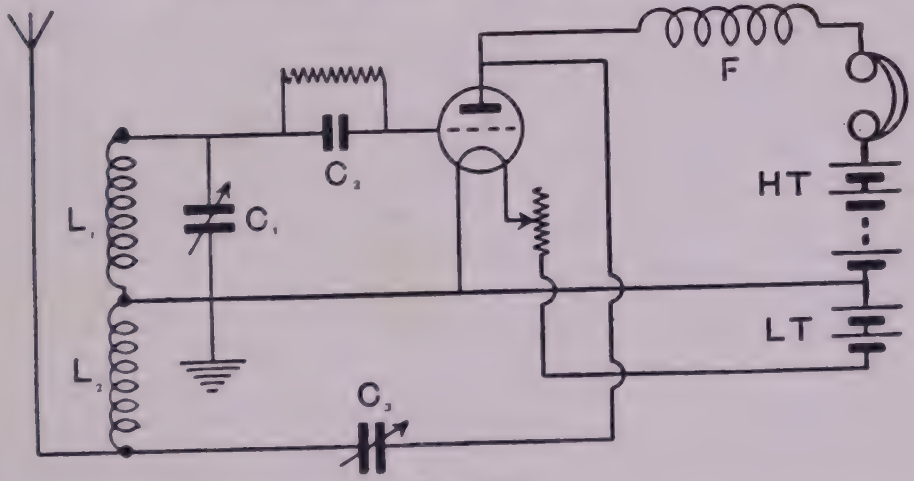


Fig. 167.

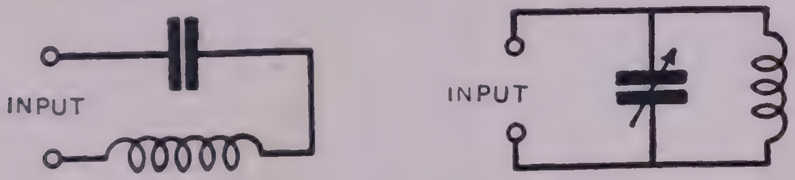
The above is suitable for a wave length range of about 100 to 320 metres. By a slight modification, however, the circuit can be adapted to plug-in coils and used for all wave lengths. Fig. 167 shows one modification for plug-in coils and the student should carefully compare the two circuits. Here $L_1$ is a plug-in coil which may be a No. 75, and $L_2$ is another plug-in coil which may be a No. 25 : with $C_1$ of capacity $\cdot 0003\mu F$

the broadcast band of waves may be dealt with. The coils $L_1$ and $L_2$ are in fixed coil holders, the coils being parallel and quite close together. The circuit is manipulated as in the case above, reaction being controlled by $C_3$ (·0001 or ·0002$\mu F$). The choke $F$ may consist of about 270 turns of No. 34 silk covered wire wound on a vulcanite tube about 1 inch in diameter. For the reception of Daventry No. 300 for $L_1$ and No. 150 for $L_2$ will be suitable, but in this case a larger choke—a No. 350 or 400 or larger—must be used.

It should be noted that in this modified form of the preceding Reinartz circuit, the reaction coil is in between the aerial and the earth, so that it acts in the double capacity of an aerial coil and (in conjunction with the condenser $C_2$) as a Reinartz reaction.

**125. Wave Traps : Acceptor and Rejector Circuits.**—If the single valve user desires still greater selectivity than he obtains with auto-coupling or loose coupling alone, some form of **wave trap** may be employed in addition. Wave traps are very simple things, the usual types consisting only of a coil of wire and a variable condenser. As the name suggests, they are used for cutting out unwanted signals so that the waves from the particular station to which the set is tuned may be received without interference. Perhaps the most common case in practice is that in which a set is being used only a few miles away from a fairly powerful transmitting station. In such cases it is often possible to tune to, and receive quite satisfactorily, a distant station when the local station is closed down, but if the latter be transmitting, the signals from it still affect the receiver and totally or partly mask any signals from the distant station. In such a case a simple wave trap which will cut out the local station will prove a boon and a blessing.

If a variable condenser and an inductance be arranged in series as indicated in Fig. 168 (*a*), the circuit will of course have a certain frequency depending on the values of the inductance and the capacity. Now if the inductance be large compared with the capacity, and if the resistance be low, it can be shown that *this circuit will readily allow the passage of oscillations of the same frequency as itself*, but will strongly oppose the passage of oscillations of any other frequency. It is evident then that a circuit like this might, for example, be tuned to the unwanted station and coupled up to the receiving set in such a way that the unwanted signals would find an easy by-pass through it, leaving the wanted signals, which are of a different wave length and frequency, to pass on to the receiver. A circuit of this type is called an **acceptor circuit.**



(a) (b)

Fig. 168.

Again, if the variable condenser and the inductance be arranged in parallel as shown in Fig. 168 (*b*), it can be shown that *the circuit will readily allow the passage of oscillations of a different frequency to itself*, but will strongly oppose the passage of oscillations of the same frequency as itself. It is evident then that a circuit like this might, for example, be tuned to the unwanted station and coupled up to the receiving set in such a way that it blocked the unwanted signals and prevented them from affecting the receiver, leaving the wanted signals to pass through to the receiver. A circuit of this type is called a **rejector circuit.**

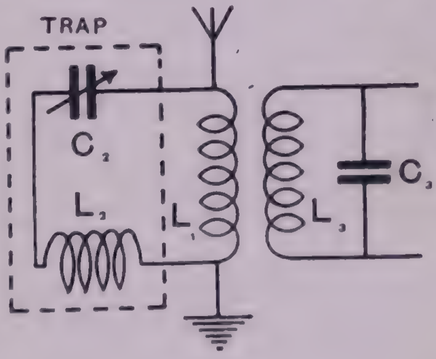


Fig. 169.

Fig. 169 indicates one method of coupling up a wave trap of the acceptor circuit type to a receiver, using inductive coupling. The trap, consisting of the coil $L_2$ and variable condenser $C_2$ in series, is tuned to the unwanted station and joined across the aerial coil $L_1$. Signals arriving at the aerial from the unwanted station find an easy by-pass *via* $C_2L_2$, so that the receiver apparatus on the right of $L_1$ in the figure is not affected by these signals and can be tuned in to the wanted signals by adjusting $C_3$ and so on in the usual way. The coils $L_1$ and $L_2$ should always be kept well away from each other, and preferably at right angles.

Fig. 170 gives a method of coupling up a wave trap of the rejector type. The trap, consisting of the coil $L_2$ and variable condenser $C_2$, is tuned to the unwanted station and put in series with the aerial as shown (it is sometimes called a **series rejector**). It therefore blocks these interfering oscillations, but allows the others to pass on to $L_1$. Of course in practice the procedure is as follows :—The aerial is joined to $A$ and the *unwanted* station is tuned in on the set : the trap is then joined up as in the figure, the aerial being now joined to $B$, and $C_2$ is adjusted until the unwanted signals disappear : the trap is now left at this, and the set tuned in to the wanted station.

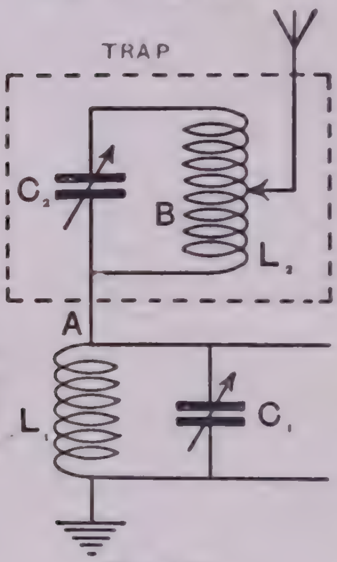


Fig. 170.

In both the preceding cases the trap it will be noticed is tuned to the *unwanted* station.

To indicate further the general principle, Fig. 171 gives both acceptor and rejector circuits, both types being tuned to the *wanted* station. The acceptor circuit $C_1L_1$ is in *series* with the aerial coil $L_2$ and both the $C_1L_1$ circuit and the $C_2L_2$ circuit are tuned to the waves to be received. The rejector circuit $C_3L_3$ is in *parallel* with $C_2L_2$, and is also tuned to the waves to be received. The required oscillations have an easy path through $C_1L_1C_2L_2$, and can therefore induce oscillations in the circuit on the right. At the same time the unwanted oscillations have an easy path through the $C_3L_3$ circuit : they are therefore drawn away from the aerial coil $L_2$ and do not produce interfering oscillations in the circuit on the right.

The student should carefully study these cases before proceeding further. As a matter of fact, the acceptor circuit and rejector circuit are merely illustrations of the resonance dealt with in Art. 88, the acceptor circuit being the resonance case dealt with in the first example quoted, where the inductance and capacity are in series, whilst the rejector circuit is the resonance case dealt with in the second example where the inductance and capacity are in parallel, the frequency of the applied pressure in both examples being equal to that of the circuit itself. Students of electrical engineering will recognise the first as what is called *series resonance*, and the second as what is called *parallel resonance*.

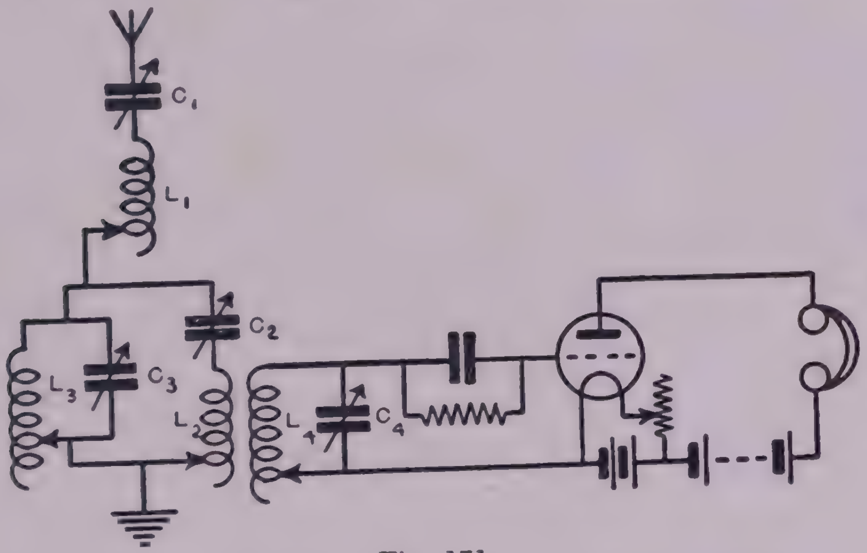


Fig. 171.

**126. Wave Trap Single Valve Circuit.**—From the preceding, the student should have no difficulty in constructing a wave trap and using it in conjunction with any of the circuits which have so far been dealt with. For the sake of completeness, however, Fig. 172 depicts a wave trap used in conjunction with a Reinartz circuit modified from that of Fig. 166. The wave trap consists of 60 turns on a vulcanite tube $2\frac{1}{2}$ inches in diameter, and its condenser is of $\cdot 0005\mu F$ capacity. Other values in the circuit are those given in preceding sections.

The best tapping point for the aerial on the grid coil depends on aerial conditions and must be found by experiment. Once found, however, the same tapping point will serve for quite a big range of wave lengths. The longer the waves the higher, really, is the tapping point.

The set is tuned in in the manner indicated in the preceding section, *i.e.* the trap is first omitted, the aerial being directly connected to the set, and the *unwanted* signals are tuned in in the usual way : the trap is then joined up as indicated, and the trap condenser adjusted until these same unwanted signals are cut out : the trap is then left where it is, and the *wanted* signals tuned in on the set in the usual way. A slight alteration in the trap condenser may be necessary during this final tuning.

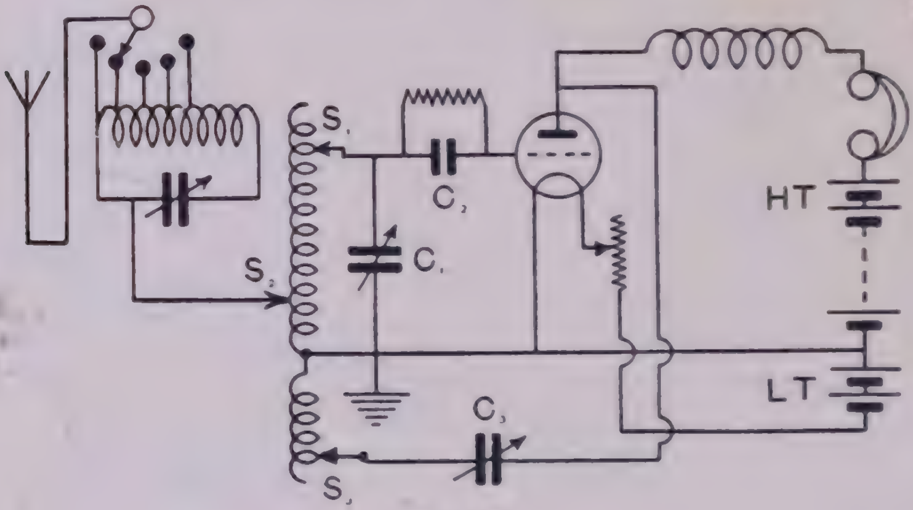


Fig. 172.

**127. Super-regenerative Single Valve Circuits.** There are many circuits specially designed to give signals louder than can be obtained as a general rule without the set oscillating. The principle of these **super-regenerative circuits**, as they are called, is to introduce intermittent damping into the circuit to prevent oscillations being set up. The intervals between these damping periods are intervals of extreme sensitiveness during which an amount of reaction can be used much greater than that which can normally be employed without the set oscillating. Two typical circuits of this type are the **Flewelling super-regenerative circuit** and the **Armstrong super-regenerative circuit.**

These super-regenerative circuits are very critical in their adjustments (they generate oscillations) and some experience must be gained in their manipulation before good results can be obtained. Carefully adjusted, however, and in the hands of an operator with some experience, they give really excellent results, magnifying weak signals enormously—signals one would hardly expect to hear at all. On the whole they are certainly not circuits which can be recommended to the beginner, but once manipulative skill backed by "wireless knowledge" is obtained, they will assuredly repay any trouble taken in constructing and operating them: the Flewelling circuit and the Armstrong circuit are briefly dealt with in the two following sections.

**128. Flewelling Single Valve Super-regenerative Circuit.**—In many of these super-regenerative circuits the intermittent damping is brought about by opposing, at intervals, the oscillations applied to the grid. In the Flewelling circuit this is done by introducing into the grid circuit capacity, which, by suitable adjustments, can be made to block and free the grid of the valve at a very high rate (15.000 times per second). One form of the circuit is shown in Fig. 173.

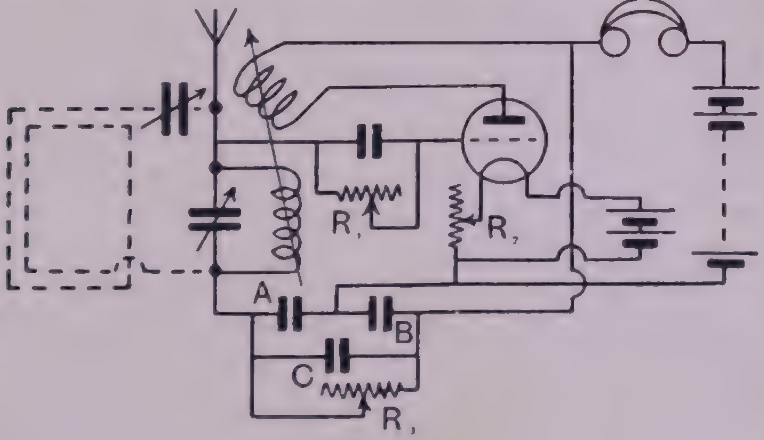


Fig. 173.

In this circuit $R_1$ is variable and its value should be from ·5 to 4 megohms. A variable resistance $R_3$ of ·5 to 4 megohms is also used. The three fixed condensers *A*, *B*, *C* are equal and of a value about ·006$\mu F$. Other values in the circuit are as previously indicated. The procedure with the circuit is as follows:—

Disconnect the condensers *A*, *B*, *C*, short circuit the wires joined to *A*, and tune in in the usual way until the best results are obtained. Then replace the condensers, and tune. The resistances $R_1$ and $R_3$ are next adjusted until an extremely high pitched whistle is heard. Then $R_1$ is adjusted until the whistle is barely audible, giving way to a throbbing noise, which again finally gives way, and pure reception comes in. When the true Flewelling effect is obtained the good signal strength and mellow tone will be appreciated.

As already indicated, the circuit is critical, and it is perhaps best to practise it on a frame aerial as shown by the dotted lines in Fig. 173 before proceeding to use it on an outdoor aerial.

**129. Armstrong Single Valve Super-regenerative Circuit.**—Many "wireless workers" were somewhat startled and not a little sceptical when a well known English wireless journal announced some time ago "All England on a Frame Aerial with One Valve." As a matter of fact the circuit in question was a type of another well known American "super" (nearly everything in wireless that hails from across the herring pond is "super" or "super super") due to Armstrong. There is no doubt but that the Armstrong circuit is extremely efficient (on short waves we have ourselves proved it truly "super" efficient), but it is tricky, and on an outside aerial neighbours are likely to be troubled with interference. Even more than in the case of the Flewelling circuit some experience and perseverance are necessary in order to obtain the good results which the circuit is undoubtedly capable of giving. Whilst, like the Flewelling, it is not a circuit which can be recommended to a beginner, a brief description of it is advisable.

Originally in the Armstrong circuit the intermittent damping previously referred to (Art. 127) was introduced by a separate oscillating valve coupled to the circuit in such a way that the oscillations produced by this valve opposed at intervals the received oscillations in the grid circuit of the main valve and so reduced the tendency to oscillate, producing those periods of extreme sensitiveness already mentioned. By the introduction of additional circuits the separate valve was then omitted, and the one valve made to act in both capacities.

One form of Armstrong circuit is shown in Fig. 174 (aerial and earth are omitted but they are joined—direct or coupled—to $L_1$ as usual); a frame aerial as in Fig. 173 is, however, strongly recommended. Briefly, the $L_1C_1$ circuit is tuned to the signals required, and the $L_2C_2$ and $L_3C_3$ circuits are tuned to the frequency required for damping. The condenser $C_2$ is variable.

A convenient value for $L_2$ is about 1200 turns and for $L_3$ 1400 turns; $C_2$ may be $\cdot 001\mu F$ and $C_3$ $\cdot 002\mu F$. Other values are as given in previous circuits. $L_2$ and $L_3$ are mounted in the usual two-coil holder.

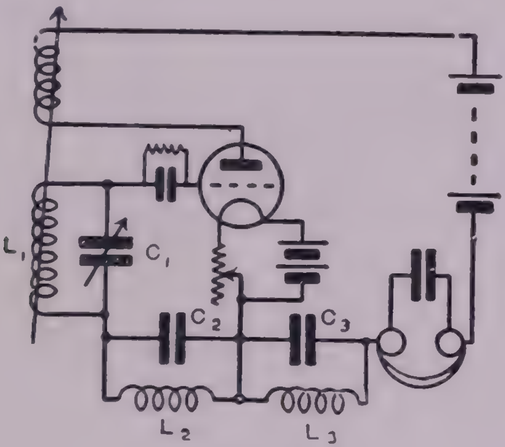


Fig. 174.

In working, the reaction coil is first loosely coupled to $L_1$: then $L_2$ and $L_3$ are gradually coupled. The set will oscillate, but if the coupling be continued the oscillation will cease. The set is next tuned in the usual way, adjustments being also made on $C_2$ at this stage for maximum results.

**130. Single Valve Amplifiers and Reflex Circuits.**—In Art. 114 was shown one method of using a single valve as a **high frequency amplifier** in conjunction with a crystal detector, and in Art. 113 one method of using a single valve as a **low frequency amplifier** in conjunction with a crystal detector was indicated. A single valve may also be used with a crystal detector in such a way that it acts both as a high frequency amplifier and as a low frequency amplifier, in which case the circuit is spoken of as a **reflex circuit**. All these are also used in conjunction with a valve detector, and are dealt with in the next chapter.

At this stage of his progress, the student should be in a position to follow the various wireless journals with real interest and understanding. Many excellent publications are available. *Modern Wireless* deals not only with constructional details and modern circuits, but with all up-to-date wireless matters in a thoroughly sound, scientific way, and can be strongly recommended to the earnest student. In addition, *The Wireless Constructor, Amateur Wireless, The Wireless World and Radio Review* and many others treat modern developments in as simple a manner as possible, and give numerous circuits and constructional hints for those experimentally inclined. The reader should examine these various periodicals and select those for *regular* reading which are most suited to his needs. In the case of a subject making such rapid advances as wireless is making, such reading is essential.

# CHAPTER XII.

## MULTIVALVE RECEIVING SETS.

**131. Introduction.**—Satisfactory though the single valve receiver is, when properly used, it has its limitations both in range and volume, and in the desire for further advances in these directions the student will soon find himself considering the question of some type of multivalve set. Quality of reproduction, of course, is something about which different people have widely different ideas. Single valve receivers can be so pushed (and are often so pushed) to secure volume that distortion becomes more or less pronounced, and whilst this does not worry some listeners who revel in the volume so obtained, others, without being expert musicians, cannot put up with it. To those in search of good volume, distance and quality, the multivalve comes sooner or later.

And the cost is not now a deterrent factor. It was once, when valve prices were high, and a six valve set, say, consumed about 18 ampere-hours of electricity every evening. But the drop in valve prices and wireless components generally, the improvements in valves, and, further, the advent of the dull emitter, have altered this, and to-day multivalve sets are largely used by listeners and by wireless experimenters and experts.

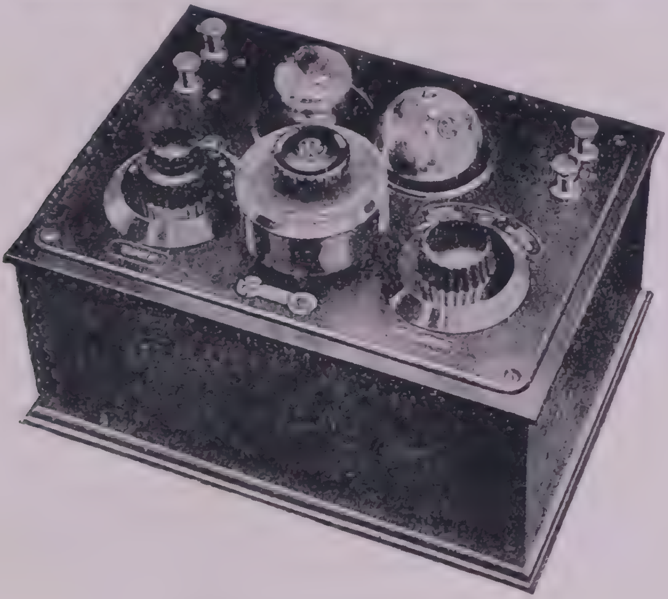
**132. Amplifying Valves.**—Before proceeding further with this chapter, the student should again read Arts. 98, 99 of Chapter VIII., and Arts. 113-115 of Chapter X.

As previously indicated, a valve may be used to amplify the weak signals just as they arrive at the aerial, *i.e.* before they are passed on to the detector valve (or crystal): this is called **high frequency amplification**, for the signals are magnified at high frequency, and the method is used in order to increase the range, *i.e.* to enable distant stations to be received. A valve may also be used to amplify the signals after they have passed through the detector valve (or crystal) : this is called **low frequency** or **audio frequency** or **note amplification,** and is used to increase the volume of sound in the telephones, or to enable a loud speaker to be used. Although there are certain special features about high frequency amplification and others about low frequency amplification, the general principle, as already indicated (Art. 99), is much the same in both. It will, of course, be understood that for high frequency amplification, the various pieces of apparatus must be suitable for high frequency work, whilst for low frequency amplification they must be suitable for low frequency work.

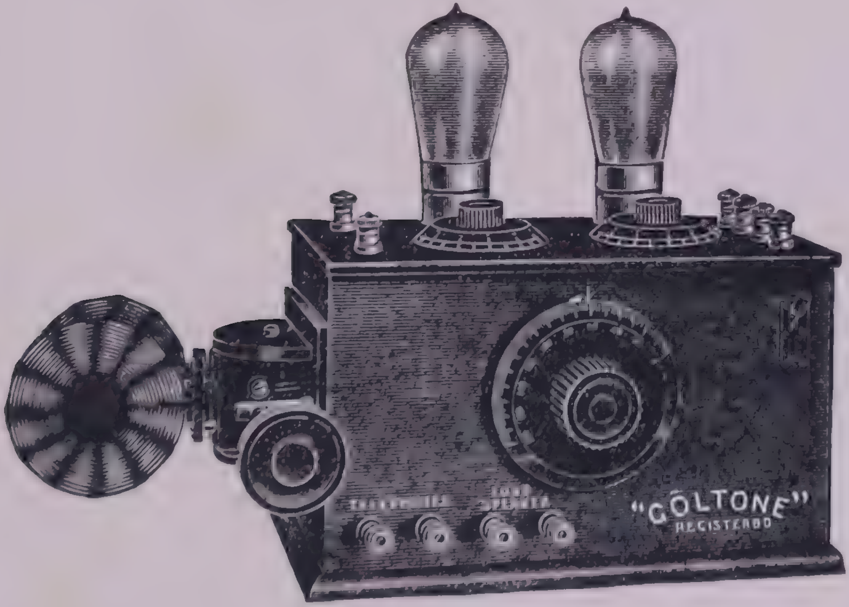
In the case of a two valve receiving set consisting of a high frequency amplifying valve followed by a detector valve, the action is briefly this :—The varying potential differences set up in the aerial inductance are applied between the grid and filament of the amplifying valve, which valve is, of course, arranged to work on the steep part of its characteristic (Art. 99). Corresponding *but magnified* changes in current are produced in the plate circuit of this valve, as already explained, and as this circuit contains either a resistance or inductance or condenser, corresponding but magnified variations in the potential differences across them are produced. These amplified potential differences are applied to the grid of the second valve (which valve is, of course, arranged to work as a detector), and the action is then the same as in the case of the single valve (detector) circuits dealt with in the last chapter. In a word, the action of the second valve (the detector) is as previously explained, but the oscillations it takes on its input side, instead of being picked up direct from the aerial, are picked up from the output side of the first valve (the amplier), which valve has taken them from the aerial and amplified or magnified them before, as it were, handing them on.

It is clear that two or three stages of high frequency amplification might be used before the detector valve comes into operation. This means that the amplified oscillations in the plate circuit of the first amplifiying valve are applied to the grid circuit of a second amplifying valve, and are further

## TYPICAL TWO VALVE RECEIVING SETS.



B.T.H. (Det. and L.F.).



Goltone (Det. and L.F.).

amplified: these are then applied to the grid circuit of a third amplifying valve and again further amplified, and so on, until finally they are applied to the grid circuit of the detector valve, the plate circuit of which contains the telephones. In practice, however, there is a limit to the number of stages of high frequency amplification which can be used owing to the tendency to set up local oscillations, as will be seen later (Art. 139).

In the case of a two valve receiving set, consisting of a detector valve followed by a low frequency or note amplifying valve, the outline of the action is just the same as in the preceding. The low frequency variations produced in the output circuit or plate circuit of the detector valve are applied to the grid of the low frequency amplifying valve, with the result that on the output or plate circuit of this valve we have corresponding low frequency variations, but, of course, magnified. These are passed on to the telephones or loud speaker.

Further, as in the preceding case of high frequency amplification, several stages of low frequency amplification may be used, the amplified (low frequency) signals, produced by the first amplifying valve being applied to the grid of a second amplifying valve, and further amplified, and so on, until finally the amplified (low frequency) signals produced by the last amplifying valve are passed on to the telephones or loud speaker.

A glance at Figs. 119, 120 will show that the bigger the amplitude of the oscillations (*i.e.* the bigger the to and fro swings) applied to the input side of a detector valve, the better is the valve acting as a rectifier: in other words, the efficiency of a valve as a rectifier or detector is greater for oscillations of large amplitude than for oscillations of small amplitude. Signals from a distant station may be too faint for efficient detection, but with a high frequency amplifying valve in front of the detector valve the amplitude is so increased that detection becomes possible and efficient. Hence the statement that high frequency amplification increases the range of a receiver, *i.e.* enables distant stations to be received.

Since low frequency amplification magnifies the signals of audible frequency which the detector would normally pass on direct to the telephones, it is clear that low frequency amplification increases the sound in the telephones. It must be remembered that low frequency amplification alone, *i.e.* without high frequency amplification, is not suitable for producing loud sounds if the original signals going to the input side of the detector valve are *very* weak, owing to the inefficiency of the detector valve for weak oscillations.

In multivalve circuits, consisting of a detector valve in conjunction with high frequency amplifying valves, there are three methods usually employed in coupling one valve to the next : these are :—

Tuned anode coupling,
Transformer coupling,
Resistance-capacity coupling.

Another method of high frequency coupling which is known as

Parallel-feed coupling

has also attracted considerable attention in recent years, and probably more will be heard of these parallel-feed circuits in the near future.

In multivalve circuits, consisting of a detector valve in conjunction with low frequency amplifying valves, there are also three methods usually employed in coupling : these are :—

Transformer coupling,
Resistance-capacity coupling,
Choke-capacity coupling.

In multivalve circuits containing both high frequency and low frequency amplifiers, any of the coupling methods for high frequency amplification may be used with the high frequency amplifiers, in conjunction with any of the coupling methods for low frequency amplification used with the low frequency amplifiers.

The main features of these various coupling methods will be dealt with in the sections which follow, and as the student is probably more interested in good quality and volume and loud speaker reproduction from a few stations than in searching for far distant stations, low frequency amplifying circuits will first be considered.

**133. Two Valve Receiving Circuit (Det. and L.F.) with Transformer Coupling.**—One type of this circuit is shown in Fig. 175, *D* being the detector valve followed by *A* the low frequency amplifying valve.

To add a low frequency amplifier to a detector it is only necessary to insert the primary *P* of a low frequency transformer (iron core—Art. 87) in the position occupied by the telephones in the usual detector circuit, the secondary *S* of the transformer being joined to the grid of the amplifying valve and to the negative of the low tension or filament battery, as shown in the figure.

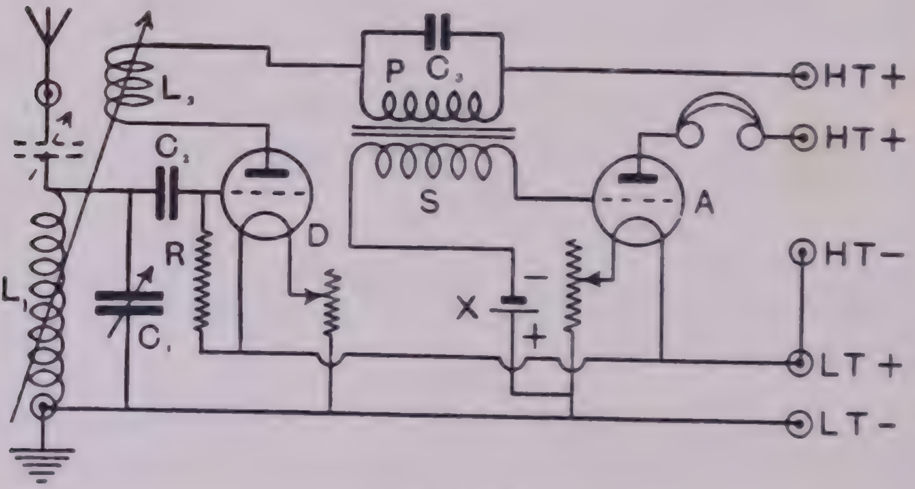


Fig. 175.

The filament resistance is also connected to the negative of the filament battery. This is done because it is essential to work the amplifying valve on the straight steep part of its characteristic curve, and with most modern valves, to ensure this it is necessary to make certain that the grid is given a certain negative bias. The potential of a grid is affected by the lead in which the filament resistance is placed, and by joining to the negative the potential drop in the filament resistance results in the grid being given a little extra negative bias with respect to the filament. Sometimes to secure the same object, one or two dry cells (grid battery) are inserted at *X*, the negative terminal being joined through *S* to the grid. With 6 volt bright emitter valves the drop in volts along the filament resistance may result in the grid being given the necessary negative bias, but in most other cases the grid battery is advisable. Moreover, grid bias improves quality and reduces the plate current, so that the high tension battery lasts longer.

It should also be noted that the grid leak of the detector valve *D* is in between the grid and the positive terminal of the low tension battery, as in the valve detector circuits depicted in Chapter XI. Further, as the one valve is functioning as a detector and the other as a note amplifier it will be observed that different tappings are made on the high tension battery, so that different voltages (stated by the makers) may be applied to the plates.

The student should carefully study the connections of Fig. 175 and compare with circuits previously given (noting any similarities and differences) before proceeding further.

Transformer coupling gives the best volume for loud speaker work, but however well transformers are built they pass on certain frequencies better than others, so that the amplification of different note frequencies is not the same, and this unevenness leads to distortion in speech and music, although with well made transformers this will not be serious. Distortion is sometimes reduced by joining a high resistance (about half a megohm) across the secondary winding, but at the same time amplification will be a little reduced. A suitable ratio for the transformer is 4 : 1, lower ratios being used for subsequent transformers if more than one amplifying valve is in use.

In Fig. 175 a direct coupled aerial is shown, but, of course, any of the better arrangements previously dealt with—auto-coupled, loose coupled, etc.—may be employed.

The action of the circuit of Fig. 175 may be briefly explained as follows :—

The circuit $L_1C_1$ is as usual tuned to the oscillations set up by the arriving waves. The varying potentials developed across $L_1C_1$ are applied between the grid and filament of the detector valve *D*, the usual grid condenser $C_g$, and grid leak *R* being in the grid circuit of this valve. The (rectified and somewhat magnified) current variations in the plate circuit of *D* produce corresponding variations of potential on the primary *P* of the transformer, which by induction are “ stepped up" in the secondary $S$. These are then applied between the grid and filament of the valve $A$, functioning as an amplifier, with the result that on the output side of this valve there are corresponding amplied variations which pass on to the telephones or loud speaker. Reaction is provided in the usual way by varying the distance between the reaction coil $L_2$ and the aerial coil $L_1$.

Suitable condenser values are for $C_1$ ·0005$\mu F$, for $C_2$ ·0003$\mu F$, and for $C_3$ ·001$\mu F$. For the broadcast band of wave lengths $L_1$ may be a No. 35 or 50 coil and $L_2$ a No. 50 or 75. For Daventry a No. 150 coil for $L_1$ and a No. 200 for $L_2$ will be suitable. It is always well to keep the reaction coil as small as possible. A suitable value for the grid leak $R$ is 2 megohms.

Again, it is sometimes an improvement to put a shunting condenser across the high tension battery. (Art. 71.) Incidentally the condenser $C_3$ across the primary $P$ of the transformer is necessary in order to "by pass" any high frequency current; sometimes a smaller value than ·001$\mu F$ will suffice, and it is advisable to have it as small as possible consistent with proper working.

The tuning in of this circuit is carried out in much the same way as already indicated for the circuits in Chapter XI.

**134. Two Valve Receiving Circuit (Det. and L.F.) with Resistance-capacity Coupling.**—As indicated in Art. 133 one objection to transformer coupling is that it results in unequal amplification of different note frequencies, and therefore produces a certain amount of distortion. With resistance-capacity coupling, on the other hand, we get uniform amplification; it amplifies signals embracing frequencies from about two hundred up to several thousand cycles per second without displaying any preference for any particular frequency. Against this advantage there is the disadvantage that resistance-capacity coupling does not give the amplification and therefore the volume of sound that transformer coupling gives; it takes about three valves resistance coupled to produce the same volume of sound as two valves transformer coupled. To those, however, who will sacrifice a little volume in order to gain in purity of reproduction, resistance coupling will meet requirements.

One type of this circuit is shown in Fig. 176, *D* again being the detector valve and *A* the note frequency amplifying valve. The resistance-capacity coupling *RC* is in the plate circuit of the detector valve *D*, being joined between the plate of that valve and the positive of the high tension battery—in the place, in fact, occupied by the primary coil *P* in the preceding circuit. *RC* should have a resistance of about 100,000 ohms. The by-pass condenser $C_3$ across *RC* performs the same duties as were mentioned in Art. 133, and its capacity should be of the order ·001 or ·0005$\mu F$.

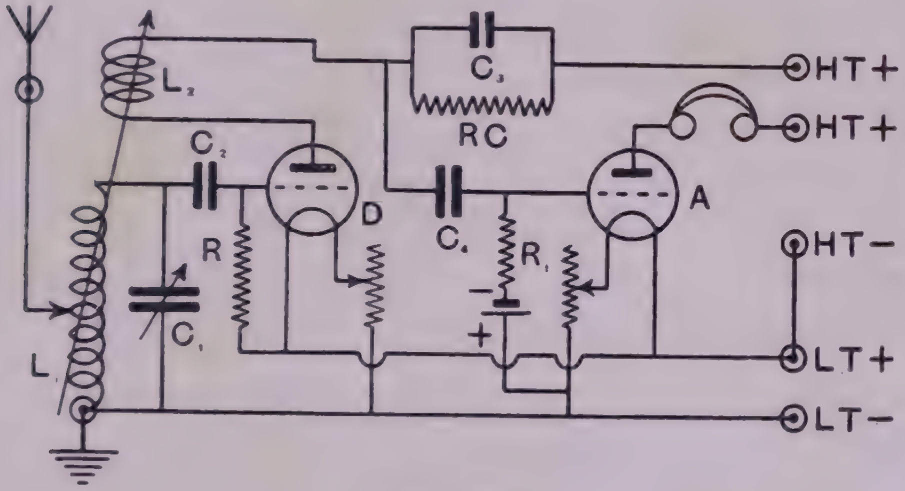


Fig. 176.

In this case the rectified (and somewhat magnified) current variations in the plate circuit of *D* produce corresponding variations of potential on *RC*, and these are applied to the grid of the amplifying valve *A* through the coupling condenser $C_4$. The grid of *A* cannot be directly connected to *RC* because it would acquire the potential of the plate of the valve *D* (which is joined to the high tension positive), and *A* would then be unable to act as an amplifier. This coupling condenser which insulates the grid of *A* from the direct high voltage supply to the plate of *D* passes on the low frequency impulses, and it is given a fairly large capacity so that it may pass on the various components of the signal equally well: its capacity may be from ·05 to ·25$\mu F$, and its insulation should be really good.

With this coupling condenser it is necessary to use a high resistance $R_1$ between the grid and filament to act in a similar capacity to the grid leak of a detector valve, *i.e.* to maintain the grid at a suitable grid voltage. It will be noted that this high resistance $R_1$ used in connection with the amplifying valve is joined to the *negative* terminal of the low tension battery or to the *negative* of the grid bias battery shown in the figure. The resistance $R_1$ may have a value of one megohm although sometimes a smaller value—·5 or ·2 megohm—will give better results. It should also be again noted that $R$, the grid leak in connection with the detector valve, is joined to the positive lead of the low tension battery.

A greater high tension voltage is necessary in the plate circuit of $D$ in order to compensate for the fall in voltage across $RC$.

The other components employed in this circuit have similar values to those given for corresponding components in the preceding circuit, and the circuit is "tuned in" in much the same way.

In Fig. 176 an auto-coupled aerial circuit is indicated, but any of those previously dealt with may be used.

**135. Two Valve Receiving Circuit (Det. and L.F.) with Choke-capacity Coupling.**—In a general way it may be said that whilst choke-capacity coupling does not give the amplification that transformer coupling does, from the point of view of signal strength it is superior to resistance-capacity coupling: on the other hand, choke-capacity coupling is inferior to resistance-capacity coupling from the point of view of pure reproduction, but a little superior to transformer coupling in this respect.

One type of this circuit is shown in Fig. 177. The choke coil $CC$ is in the plate circuit of the detector valve $D$, being joined between the plate of that valve and the positive of the high tension battery. Suitable iron-core chokes can be purchased. The by-pass condenser $C_3$ should have a capacity of the order ·0003 or ·0005$\mu F$.

In this case, as in the previous circuit, the rectified current variations in the plate circuit of $D$ produce corresponding variations of potential on the choke, and these are communicated to the grid of the amplifying valve $A$ through the coupling condenser $C_4$. This condenser, together with the high resistance $R_1$, are necessary for the reason already explained in Art. 134. In this case the coupling condenser should have a capacity of between ·01 and ·1$\mu F$, a usual value being ·05$\mu F$. The resistance $R_1$ should be of the order ·5 or 1 megohm : as in the previous circuit it is joined to the negative terminal of the filament battery or to the negative of extra grid cells to maintain the grid at the necessary voltage.

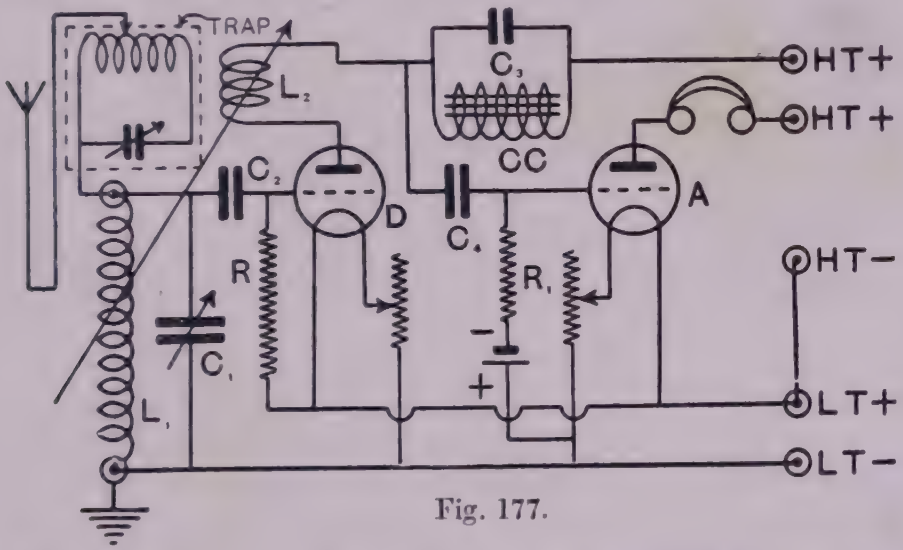


Fig. 177.

The other components employed in this circuit have similar values to those given for the corresponding components in previous circuits, and it is tuned in the same way. Any of the aerial arrangements described in preceding pages may be employed : a wave trap is shown in the aerial circuit of Fig. 177.

**136. Two Valve Receiving Circuit (H.F. and Det.) with Tuned Anode Coupling.**—If it is desired to bring in the more distant stations, some form of high frequency amplification must be used, and the most popular, and perhaps the most efficient, is the tuned anode (or rejector circuit) method of coupling shown in Fig. 178, where *A* is the high frequency amplifying valve in front of the detector valve *D*.

In the plate circuit of the valve *A* is a coil $L_3$ and a variable condenser $C_2$ in parallel with it. For the broadcast band of wave lengths $C_2$ may be ·0002$\mu F$ capacity (·0005$\mu F$ capacity for longer waves); a suitable coil for $L_3$ is a No. 50 or 75 for the broadcast band. It will be noted that $C_2$ and $L_3$ constitute a rejector circuit. Other coil sizes and capacity values are the same as those for corresponding components in previous circuits.

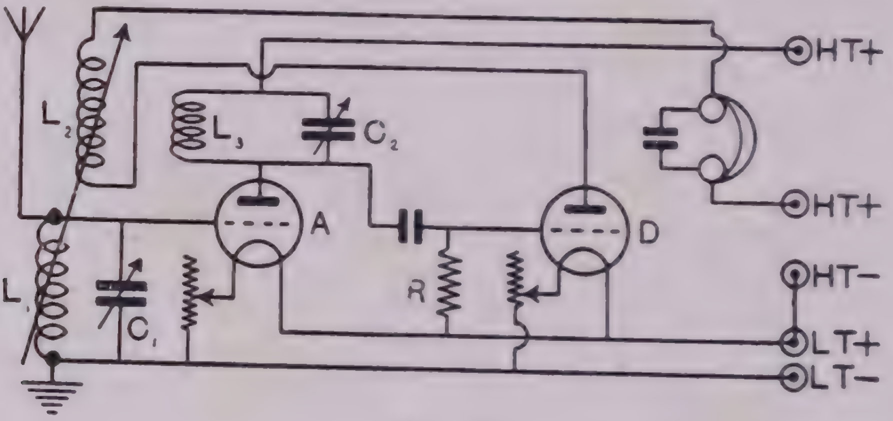


Fig. 178.

Reaction is obtained by coupling the coil $L_2$ in the plate circuit of the detector valve $D$ with the aerial coil $L_1$. There is less tendency to cause interference with other listeners in the vicinity if $L_2$ be coupled with the anode coil $L_3$ instead of with the aerial coil $L_1$, but results are not so good: sometimes the reaction coil is in two portions connected in series, reaction being applied both to the anode coil and the aerial inductance (compare Arts. 123, 142).

It should again be noted that the grid leak of the detector valve is joined to the positive terminal of the filament battery, that the filament resistances of both valves are joined to the negative terminal, and that the grid return from the first valve—the amplifier—is also joined to the negative terminal.

In this arrangement both the $L_1C_1$ circuit and the $L_3C_2$ circuit are tuned to the desired frequency (and wave length). The varying potentials applied to the grid of the amplifying valve $A$ produce amplified oscillations in the plate circuit of $A$, *i.e.* corresponding (amplified) potential differences are set up) across $L_3C_2$ which is tuned to resonance with the oscillations. Finally these are fed to the grid circuit of the detector valve, the plate circuit of which includes the telephones.

In tuning, the reaction coil is first moved as far back from the aerial coil as possible, $C_2$ is set at a small reading and then $C_1$ is slowly rotated. If no signals are heard $C_2$ is set at a larger reading, and $C_1$ again slowly rotated and so on until the best signals are obtained. The reaction coil is then moved slowly towards the aerial coil, further slight adjustments of $C_1$ and $C_2$ being made as necessary.

It should be observed that when the circuit $L_3C_2$ is sharply tuned, it is acting as a rejector circuit, and interfering oscillations applied to the grid will not be amplified for the effective resistance of the tuned anode to oscillations of a different frequency to that to which it is tuned is small (see wave traps, Art. 125) : hence tuned anode coupling gives a very selective amplifier.

The tendency for the high frequency valve to oscillate is the chief trouble encountered in this circuit : this defect is dealt with in Art. 139.

**137. Two Valve Receiving Circuit (H.F. and Det.) with Transformer Coupling.**—Tuned transformer coupling between the high frequency amplifying valve and the detector valve is shown in Fig. 179, and the circuit diagram should be readily understood.

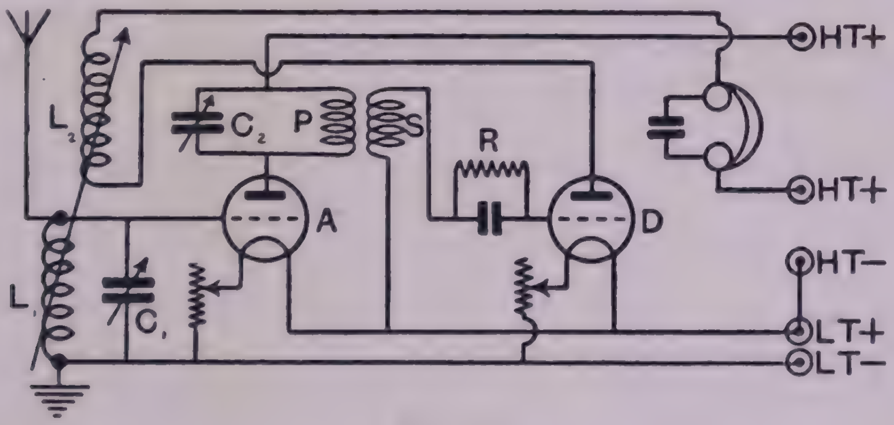


Fig. 179.

The secondary $S$ of the transformer in the plate circuit of the amplifying valve $A$ is connected as indicated between the grid and filament of the detector valve $D$. Since the aim is to apply as high a voltage as possible to the grid of $D$, the secondary $S$ should be tuned as well as the primary $P$, but it is found that with the tight coupling which exists between $P$ and $S$ in practice, the one tuning condenser $C_1$ in the primary tunes both $P$ and $S$. High frequency transformers can, of course, be purchased, but home-made coils can be used provided due care is exercised in the making of them. For the broadcast band a coil consisting of about 12 turns of 24 gauge wire wound on a tube 3 inches in diameter will make a convenient primary, whilst about 40 turns wound on a tube $2\frac{1}{2}$ inches diameter will serve as a secondary, the latter being fixed inside the former. The tuning condenser in the circuit of $P$ should have a capacity of about $\cdot 0002 \mu F$. Other values for the various components in this circuit are the same as for corresponding components in previous circuits.

The grid leak $R$ of the detector valve in this circuit may be placed across the grid condenser, for $S$ is quite separate from $P$ (and the positive high tension), and is joined to the positive of the low tension battery.

In the figure the reaction coil is coupled to the aerial inductance : sometimes it is applied to the transformer windings, and sometimes it is in two portions connected in series, reaction being applied to both the transformer windings and the aerial inductance (see Art. 136).

As with the tuned-anode coupling (Art. 136) the control of oscillation with this circuit sometimes presents difficulty : this is dealt with in Art. 139.

### 138. Two Valve Receiving Circuit (H.F. and Det.) with Resistance-capacity Coupling.

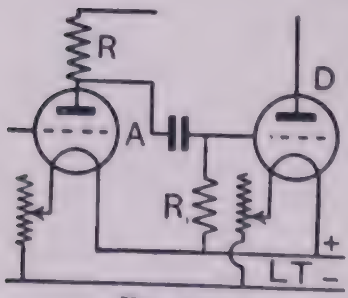


Fig. 180.

—Resistance-capacity coupling between the high frequency amplifying valve and the detector valve is shown *in outline* in Fig. 180, and the circuit will be understood from what has been said in previous sections.

This coupling method does not lead to the degree of amplification which is obtained from the preceding tuned arrangements. On the other hand it gives good results on high wave lengths (say over 1500 metres), the amplifying circuits are not so liable to self oscillation, the resistance of the plate circuit is constant over a big range of frequencies, and distortion is a minimum. Of course additional high tension is required to compensate for the fall in voltage across the resistance.

As in previous circuits the varying potentials set up across the resistance are applied to the grid of the detector valve, the usual grid condenser and grid leak being employed.

**139. Oscillation with High Frequency Valves.**—Reference has frequently been made in preceding sections to the fact that high frequency valves display a great tendency to oscillate even when no reaction is intentionally applied, and several methods have been devised for the control of this oscillation : **neutrodyning**, as it is termed, is one of the best of these various methods, and neutrodyne circuits are now largely employed in cases where high frequency amplification is made use of.

As explained in Art. 119, the object of reaction is to feed back energy from a plate circuit to a grid circuit to compensate for the damping or waste of energy in the grid circuit : it was also indicated that if too much energy be fed back—if the feed back is more than sufficient to make up for the damping—the valve will oscillate.

Now high frequency amplifying valves tend to oscillate because there is often marked capacity inside the valve between the plate and grid, and this capacity acts just in the same way as the reaction condenser dealt with in certain of the preceding circuits : it feeds back energy from the plate circuit to the grid circuit, and if this be excessive, oscillations are set up.

One method of partially controlling this is to insert a resistance in the tuned circuit in such a way that it produces a certain amount of damping, which tends to check oscillation. Thus if a tuned anode circuit be bridged by a resistance, having a value of about ·1 to ·5 megohm, the resulting damping will tend to control oscillation : a similar result will follow if a resistance of about 1000 ohms be put in series with the inductance or in the connection between the tuned circuit and the high tension battery.

Another method is to employ *negative reaction, i.e.* to couple a reaction coil in such a way that it acts in the opposite direction to the reaction caused by the valve capacity, and to so adjust this negative reaction that it just cancels the effect of the valve capacity (or inter-electrode capacity as it is more frequently called).

Yet another method is to employ a potentiometer, and to give a slight positive potential bias to the grid of the high frequency amplifying valve which again will damp down the effect of the valve capacity. The method is indicated in Fig. 181, where *P* is the potentiometer. (See Art. 242.)

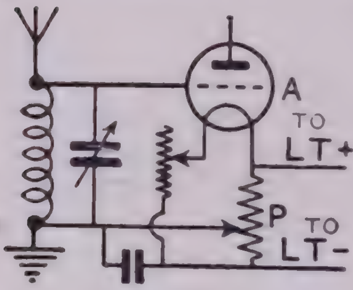


Fig. 181.

Neutrodyning might be said to be a method of applying negative reaction to cancel the reaction caused by the valve capacity: moreover, it does this without reducing the efficiency to the extent that other methods do: further, once set, it automatically adjusts itself when different wave lengths are being received.

**140. Two Valve Neutrodyne Circuit (H.F. and Det.).**—Imagine a point to be selected on the plate side of the H.F. valve which has a potential at any instant of *opposite sign* to the potential of the plate at that instant. Imagine further that this point is joined through a variable condenser to the grid of the valve. Clearly it will be possible to feed back energy to the grid circuit *opposite* to the feed back due to the valve capacity, and by adjusting the capacity of the variable condenser it will be possible to make these two opposing influences exactly equal so that they balance each other. The impulses delivered by one will be equal and opposite at any instant to the impulses delivered by the other, so that the set as a whole will remain quiet and stable: this is the elementary principle of the neutrodyne circuit.

One type of neutrodyne circuit is depicted in Fig. 182. Referring to the figure it will be seen that the primary *P* of a high frequency transformer is included in the plate circuit of the amplifying valve *A*. The secondary *S* of this transformer has one end connected through a small neutrodyne condenser $N$ to the grid of the valve and the other end connected to the *negative* lead of the low tension battery. The neutrodyne condenser should have a maximum capacity about twice the valve capacity (this latter may be of the order 10 to 12 $\mu\mu F$). Several types of neutrodyne condensers are on the market. The tuning condenser across the primary of the transformer should have a capacity of $\cdot 0003 \mu F$. From an examination of the primary and secondary circuits and from the theory given in preceding pages, it will be clear that a back coupling effect will be obtained through the neutrodyne condenser *opposite in phase* to that produced by the plate-to-grid capacity of the valve : hence the two can be made to neutralise as stated above.

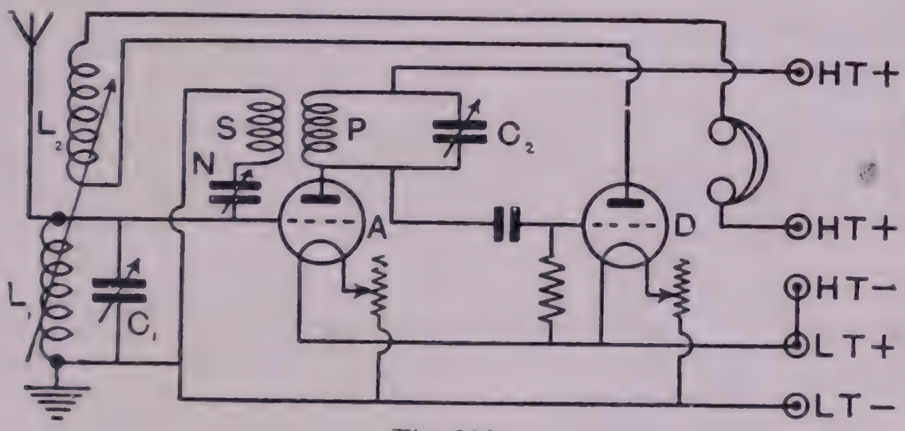


Fig. 182.

In working with this circuit the procedure is as follows. With the usual No. 35 or 50 coil for $L_1$, the aerial and earth disconnected, and the reaction coil short circuited, the condenser $C_1$ is set at about 10° and $C_2$ rotated : in certain positions the set will oscillate. Next adjust the neutrodyne condenser and it will be found that the range of the oscillations on rotating $C_2$ is being reduced ; continue this until the set practically does not oscillate when $C_2$ is moved to and fro. Now set $C_1$ at 20°, and again rotate $C_2$ and, if necessary, slightly adjust the neutrodyne condenser for no oscillation. This is continued until a setting of the neutrodyne condenser is obtained, such that there is no oscillation for any positions of $C_1$ and $C_2$.

Having got the neutrodyne condenser to its correct position it is allowed to remain there, and the set is tuned in in the usual way, the aerial and earth being now connected to the set, and a No. 50 or 75 coil being placed in the reaction.

Another method of neutrodyning, known as the split-coil method, is indicated *in principle* in Fig. 183. The coil *L* in the plate circuit of the H.F. valve *A* has a centre tapping which is joined to the positive of the high tension battery. Special coils, *e.g.* the "Dimic" and others, are now on the market for the purpose. One end of the coil is connected to the plate of *A* and the other end *via* the neutrodyne condenser *N* to the grid of the valve. The coil *L* has a variable condenser *C* across it, and the *LC* circuit is tuned just as in the case of the tuned anode coupling methods previously dealt with.

A little consideration and examination of the figure will show that since the H. T. positive is joined to the middle of *L* (and therefore the two parts of the coil *L* are equal) the connections are such that by adjusting *N* it will be possible to make its capacity neutralise the plate-to-grid capacity of the valve. In other words, the feed back due to the valve capacity will be cancelled and the circuit will be stable: moreover it will remain stable however *C* is altered, and even if *L* be changed for another centre tapped coil of a different range. Other methods of neutrodyning are also in use.

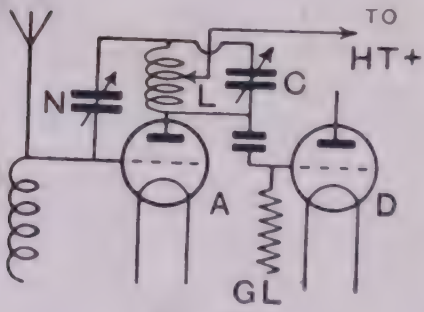


Fig. 183.

The neutrodyne has repeatedly been spoken of in the press as a distinctly American invention. As a matter of fact Mr. J. Scott-Taggart took out a British neutrodyne patent in January 1923 whilst Professor Hazeltine took out the American patent in April 1923, the two scientists having worked quite independently. Unfortunately, whilst American manufacturers realised its possibilities at once, British manufacturers did not, with the result that the Scott-Taggart patent was subsequently sold, the purchasers being the Hazeltine Corporation of America. To-day the merits of neutrodyning are recognised and many American sets, licensed under the Scott-Taggart patent are being sold in this country. "Wireless" abounds with similar ironical situations.

**141. Parallel Feed Circuits.**—A brief reference may be made to at least one type of this circuit in passing. In the tuned anode circuit of Fig. 178 the supply from the H.T. battery to the plate of the high frequency amplifying valve $A$ is through the coil $L_2$, whilst the path of the high frequency component of the plate current is *via* the high tension battery side of the circuit to the filament. In the "parallel feed" circuit shown in Fig. 184 the supply to the plate of the high frequency amplifying valve is through the coil $L_1$, whilst another path is provided for the high frequency component, namely *via* the condenser $C_1$ and the tuned circuit $L_2C_2$ which is in between the grid and filament of the detector valve. The principle of action is the same as that already given in preceding pages and the student should think this out carefully before proceeding further. A convenient value for $L_2$ is about No. 75, and for $C_2$ ·0005$\mu F$. The choke $L_1$ may be a No. 200, or better, a No. 250. Other components have the same values as those of corresponding components in preceding circuits.

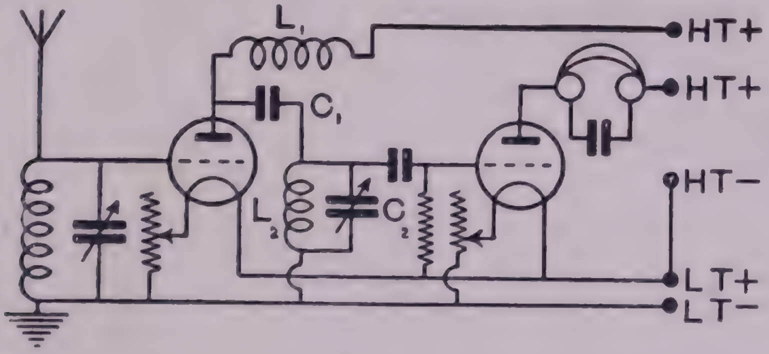


Fig. 184.

There are other types of parallel feed circuits, and without doubt they result in good amplification, and at the same time, stability. For full details of their theory and application to the design of receiving sets the student is referred to Mr. Hartt's article on Parallel Feed Circuits in *Modern Wireless* of April 1926.

**142. Three Valve Receiving Circuits.**—The student who has thoroughly mastered the circuits already given in this and the preceding chapter should have no difficulty in understanding the construction and action of receiving sets involving the use of three (or more) valves.

Fig. 185 depicts the connections of a three valve set consisting of a high frequency amplifying valve *A* followed by a detector valve *D*, this being followed by a low frequency amplifying valve *C*. Tuned anode coupling $C_2L_2$ is employed between the first amplifying valve and the detector, and transformer coupling *PS* between the detector and the note amplifying valve. The reaction coil *R* is in the plate circuit of the detector valve *D*, and is coupled, not to the aerial, but to the coil $L_2$.

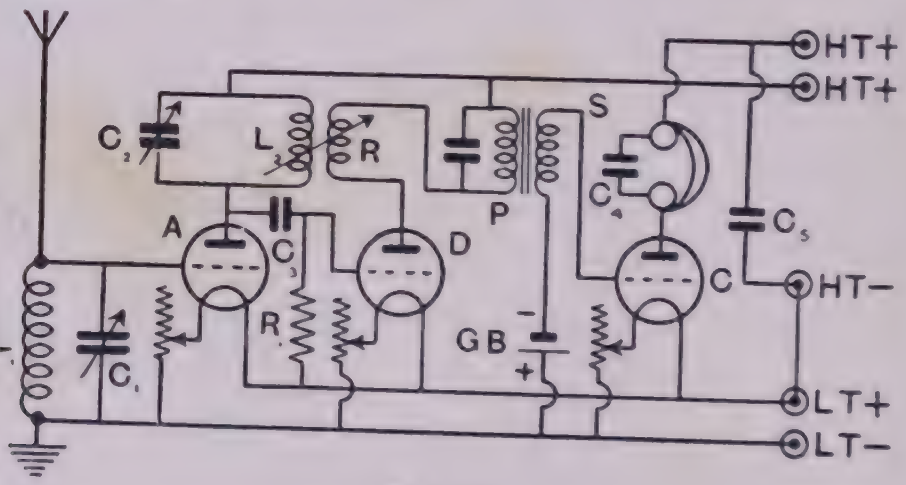


Fig. 185

The coil numbers and capacity values are the same as those given in preceding circuits in which they are performing similar duties. Thus for the broadcast band $L_1$ may be a No. 35 or 50 coil, $L_2$ a No. 50 or 75 coil, and *R* a No. 50 or 75. The condenser $C_1$ may be of ·0005$\mu F$ capacity and $C_2$ of ·0003$\mu F$ capacity. The grid condenser $C_3$ has a capacity of ·00025$\mu F$ and the grid leak $R_1$ a resistance of 2 megohms. $C_4$ has a capacity of ·002$\mu F$ and the condenser $C_5$ which is joined across the plate battery has a capacity of ·25 to ·5$\mu F$. The student should again note in this and succeeding circuits the negative bias applied to the grid of the note amplifying valve in order to get the modern valve of this type on to the right part of its characteristic.

With the reaction coil well back from $L_2$, the set is tuned in by varying the two condensers $C_1$ and $C_2$: these may be varied simultaneously or as indicated in Art. 136. When the best signals are obtained, the reaction coil is brought nearer to $L_2$ and $C_1$ and $C_2$ are again slightly adjusted as necessary.

One drawback to the above circuit is the tendency to lack of stability of the high frequency amplifying valve, in other words, the tendency for self-oscillation whenever the grid and plate circuits of this valve are brought anywhere near in tune with each other. This weakness can be partially remedied by giving a *positive* bias to the grid of the high frequency valve, as already indicated (Art. 139), so that many receiving sets arranged with this circuit have the grid of the first valve connected to low tension positive instead of to low tension negative as in Fig. 185.

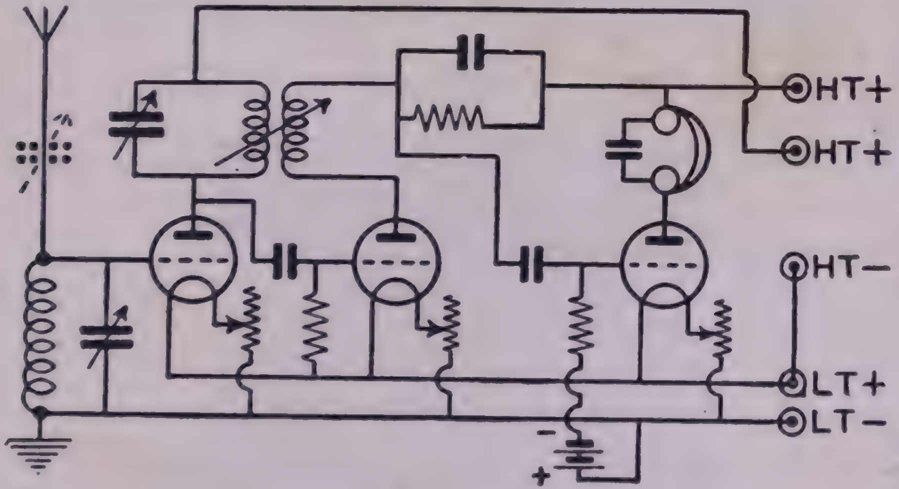
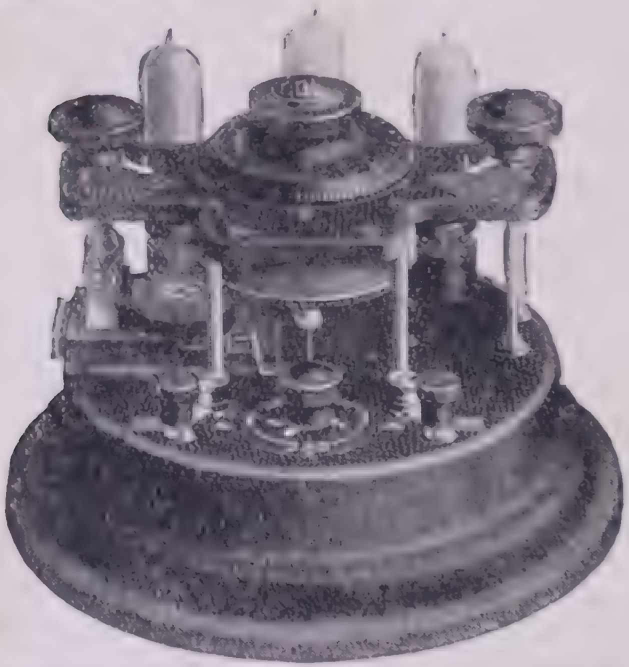


Fig. 186.

As another example of a simple three valve receiving circuit Fig. 186 may be consulted. It consists of a high frequency amplifying valve, followed by a detector valve, this again being followed by a note amplifying valve. Tuned anode coupling is arranged between the first valve and the second, and resistance-capacity coupling between the second and third; it will be remembered that this latter coupling does not give the volume that transformer or choke coupling produces, but

# TYPICAL THREE VALVE RECEIVING SETS.



(1) Gecophone (Det. 2 LF).

(2) Cosmos (HF. Det. LF).

it gives the purest reproduction. Reaction is obtained by coupling a coil in the anode circuit of the detector valve to the tuned anode coil of the first valve. Coil numbers and capacity values are as given in preceding circuits, and the method of tuning in is the same as in the last example. The drawback to this circuit is, of course, the same as to the preceding, viz. lack of stability in connection with the high frequency amplifying valve. When manipulated with due care, however, the circuit is a good all round one for listening-in purposes.

Reference has been made to the employment of a positive bias on the grid of the high frequency valve in order to secure stability. Another method of stabilising, also indicated in Art. 139, is the employment of a potentiometer, and Fig. 187 depicts a somewhat similar circuit to the preceding—high frequency, detector, low frequency—in which the potentiometer method of control is used. As a variation on the preceding circuits, however, choke-capacity coupling is shown between the detector and low frequency amplifying valve, tuned anode coupling being employed between the first two valves as before. As mentioned in Art. 135 choke coupling does not give the volume of sound that transformer coupling gives (although it is better than resistance coupling in this

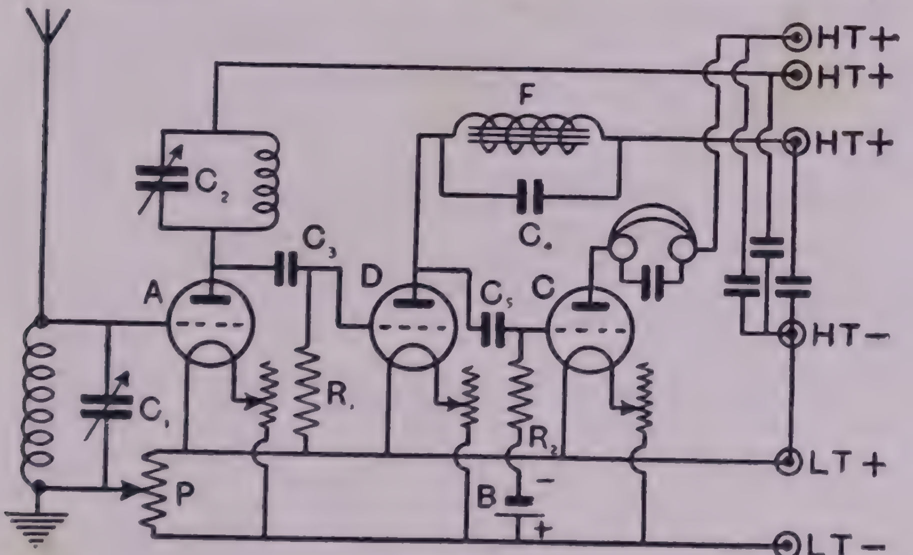


Fig. 187.

respect), but the quality is much better (although not so good as with resistance coupling).

After the circuits already given, the student should find that Fig. 187 is self-explanatory. The potentiometer $P$ and the choke $F$ may be any of the good standard instruments which are placed on the market for their particular purposes. The capacity of $C_4$ should be about ·0001$\mu F$ and of $C_3$ about ·013 to ·015$\mu F$. The resistances $R_1$ and $R_2$ should each be 2 megohms. Other values are the same as for corresponding components in previous circuits.

In tuning in, the potentiometer is set at or near its mid-position, the condensers $C_1$ and $C_2$ are varied as usual until a good signal is obtained, and then the potentiometer is adjusted until the signals are at their maximum. Turning the potentiometer *towards the negative end* brings the receiver nearer to the oscillation condition which, of course, must not be overstepped: turning it away from the negative end *towards the positive end* stabilises the circuit. A reaction coil is not necessary in this circuit, signal strength being varied by means of the potentiometer. Students working on a circuit of this type will soon become accustomed to this method of controlling reaction.

The potentiometer method was at one time the chief method employed for stabilisation of the H.F. valve and it is still largely used; the drawback to it is that the positive bias—big with some sets—applied to the grid tends to reduce the selectivity of the set.

It will be noted that negative bias is again given to the grid of the note amplifying valve $C$ by means of the small battery $B$. Incidentally the higher the plate voltage the larger the negative bias which must be applied to this grid. The condensers joined between each plate circuit and the high tension negative should have a capacity of about ·5$\mu F$ in this circuit.

As explained in Art. 139 one of the best methods of stabilising a set when high frequency amplification is used is the method employing the neutrodyne principle, and Fig. 188 depicts a further application to the circuits given above—high frequency, detector, low frequency. Tuned anode coupling is again used between the high frequency amplifying valve and the detector valve, and transformer coupling between the detector and the low frequency amplifying valve. The neutrodyne principle has already been dealt with, but owing to its importance, and the growing tendency to apply it to the best modern receivers, a few remarks on the circuit may again be given.

Coupled (fixed) to the anode coil $L_2$ is the coil $N$, one end of which is joined to the grid of the high frequency valve through the small neutrodyne condenser $C$; the other end communicates with the negative of the low tension battery. As explained (Art. 140) this results in a back coupling effect through the neutrodyne condenser opposite in phase to that of the valve plate to grid capacity, so that the two effects can be made to neutralise and great stability is obtained. The coils $L_2$ and $N$ may consist of the two windings of the usual plug-in transformer, but special "neutrodyne units" can also be purchased.

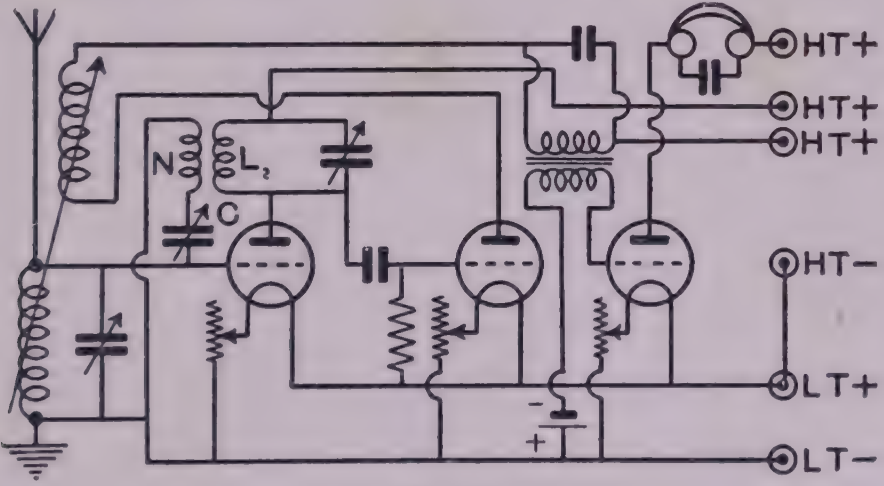


Fig. 188.

The coil numbers and capacity and resistance values of other components are the same as those already given in the previous circuits.

The method of working with a neutrodyne circuit is indicated in Art. 140 and may merely be briefly summarised here. To begin with, the aerial and earth are *not* connected to the set and the reaction coil is short-circuited. The aerial tuning condenser is set at about 10° or 20°, the neutrodyne condenser is set at its lowest reading, and the anode condenser is rotated. The set will oscillate, such oscillation being indicated by a rustling sound or a click in the telephones. The neutrodyne condenser is then adjusted, when it will be found that the range of the oscillations on rotating the anode condenser is being reduced. This is continued until a position of the neutrodyne condenser is found such that there is little or no oscillation. The aerial tuning condenser is then given another setting, $C_2$ rotated, and the neutrodyne condenser again slightly adjusted if necessary for no oscillation. This is repeated until finally a position for $C$ is found such that there is no oscillation for any position of $C_1$ and $C_2$.

The neutrodyne condenser is kept at this reading and the receiving set now worked as previously explained.

So far, the three valve receiving circuits which have been dealt with comprise a high frequency amplifying valve followed by a detector and then by a low frequency amplifying valve, and whatever other combination is adopted the principle is the same. We may have, of course, two stages of high frequency amplification followed by a detector, or a detector followed by two stages of low frequency amplification, and the coupling methods adopted may be any of those previously given. An extremely useful three valve circuit for the listener-in consists of a detector followed by two stages of low frequency amplification, transformer coupling being used between the first and second valves and resistance-capacity coupling between the second and third. A diagram of this is not given for the reason that the method is adopted in the still better four valve circuit depicted in Fig. 191. The student, however, should now be able to design such a circuit, and a set of this type will well repay the trouble in construction both from the point of view of good loud speaker results from a few stations and good quality of reproduction.

**143. Receiving Circuits employing more than Three Valves.**—At this stage of his progress the student should be in a position to understand the many up-to-date multivalve circuits which are designed and appear from time to time in the various wireless journals, and these he should regularly study, trying out himself as many circuits and modifications as

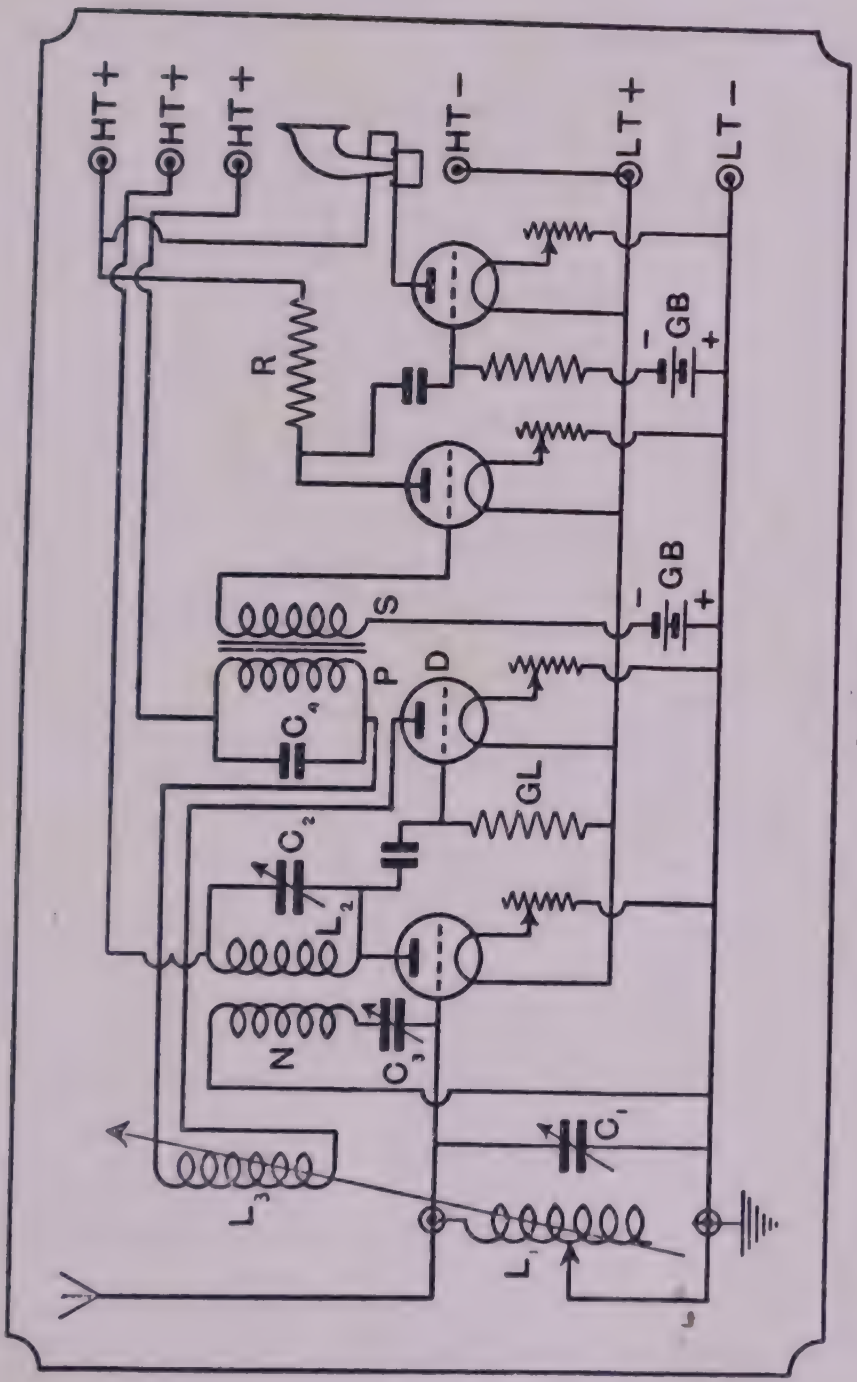


Fig. 189.

circumstances permit. As further help in this direction, however, we give Fig. 189—a four valve circuit which embraces most of the modern tendencies in the design of wireless receivers.

It will be observed that the circuit consists of a high frequency amplifying valve followed by a detector, this again being followed by two stages of note amplification. Tuned anode coupling $C_2L_2$ is employed between the first valve and the second valve, transformer coupling *PS* between the second and third and resistance-capacity coupling *R* between the third and fourth. The neutrodyne principle *C N* is used to stabilise the high frequency amplifying valve. Negative grid bias *GB* is used on both the low frequency amplifying valves. Arrangements are made for different plate voltages to be used with the different valves. The values of the various components are the same as those given in preceding circuits. *GL* is the grid leak in connection with the detector valve *D* and it is joined to low tension positive as usual.

All the points in modern design given in this circuit have been dealt with in preceding pages, and need only be briefly referred to again here.

The once popular potentiometer method of stabilising the H.F. valve has, as already indicated, been largely superseded by the neutrodyne method, which ensures stability with efficiency even when two or more stages of high frequency amplification are employed, and this method is used in Fig. 189.

Again, at one time, all the valves in a set were supplied with the same plate voltage. If general purpose valves are used this is fairly satisfactory, but manufacterers now make valves for specific purposes—naturally they do their work more efficiently—and hence different plate voltages are necessary according as to whether they are high frequency, detector, or low frequency valves. Thus in the circuit of Fig. 189 the detector valve requires a lower plate voltage than the high frequency valve, and the note amplifiers require a larger voltage in order to get on to the right position of the characteristic curves for such valves.

Further negative bias is almost invariably given to the grids of the low frequency amplifying valves; this brings the modern valve designed for this purpose on to the proper part of its characteristic, as frequently mentioned in preceding pages.

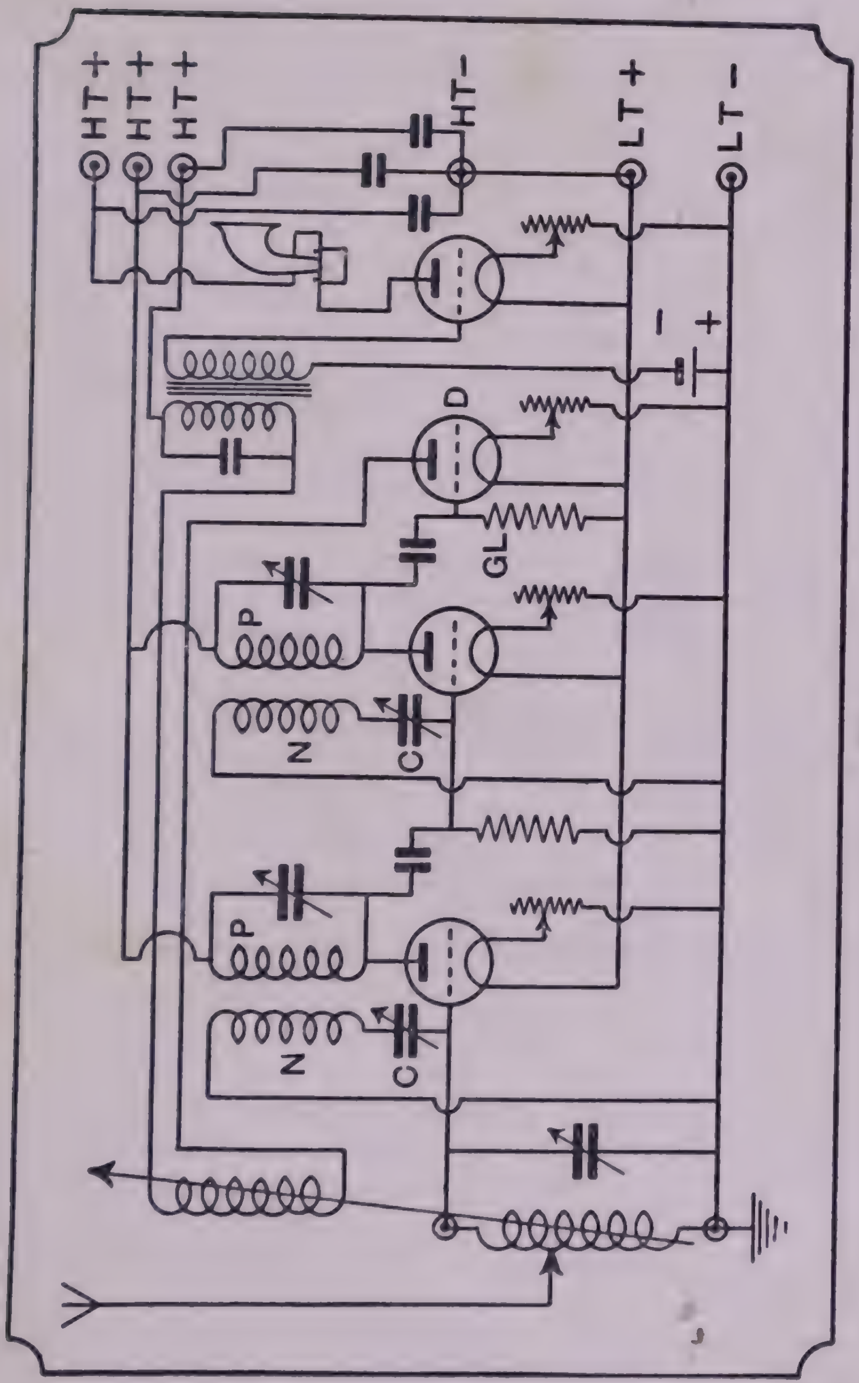


Fig. 190.

Finally, only one stage of transformer coupling is employed, to avoid the distortion which occurred when two or more such transformers were used. As also mentioned on several occasions, resistance-capacity coupling gives the purest reproduction.

For simplicity the three condensers which should be joined between each high tension positive and the high tension negative are not shown in Fig. 189.

Another four valve receiver circuit is depicted in Fig. 190. This embraces two stages of high frequency amplification, followed by a detector and one stage of note amplification. The neutrodyne principle is used with each of the high frequency amplifying valves, *i.e.* in each case the secondary coil *N* of the transformer *NP* in the plate circuit of the high frequency valve is connected through a small neutrodyne condenser *C* to the grid of the valve, the other end of *N* in each case being joined to the negative of the low tension battery. Transformer coupling is used between the third and fourth valves as indicated. *GL* is again the grid leak in connection with the detector valve *D*, and it is joined to low tension positive.

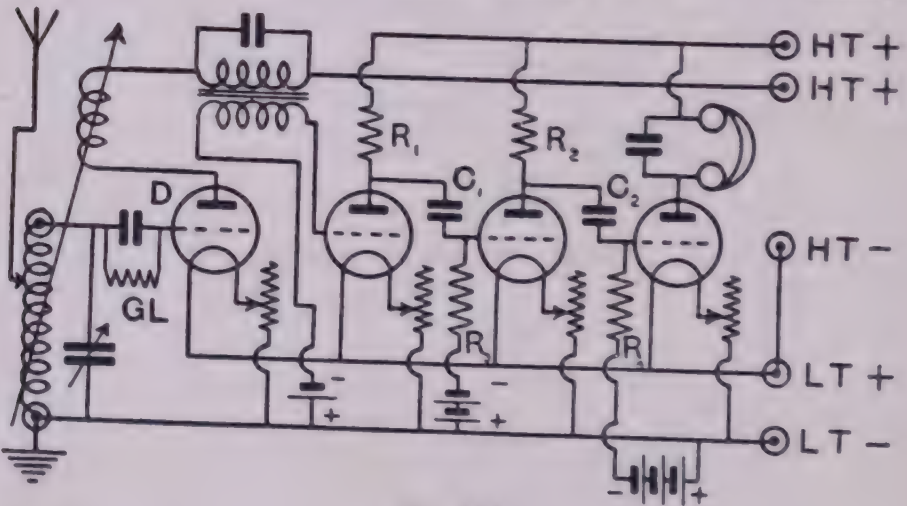


Fig. 191.

To the listener-in who has little desire for experimental work but simply requires really good music and speech on the loud speaker from a few stations, with more distant stations on the telephones, and at the same time needs a set which is easily manipulated, the circuit shown in Fig. 191 can be recommended. It is a four valve receiver consisting of a detector followed by three stages of low frequency amplification, transformer coupling being used between the first two valves, and resistance-capacity coupling between the others. The student who has carefully studied the circuits given in preceding pages will have no difficulty in understanding this arrangement. The resistances $R_1$ and $R_2$ should each be about 100,000 ohms, whilst $R_3$ and $R_4$ should each be about ·5 megohm. The condensers $C_1$ and $C_2$ should each be of capacity ·25$\mu F$. Dull emitter valves which take only about $\frac{1}{4}$ ampere are recommended for the amplifying valves, the high tension voltage required being about 110 volts. The values for the other components are the same as for corresponding parts in previous circuits. This circuit is strongly recommended to those who are anxious to secure really good and pleasing loud speaker results to which no exception can be taken even by those whose musical qualifications are of a high standard.

**144. Reflex Circuits.**—It is possible by specially arranging the circuit to make one valve do the duty of two valves, *i.e.* to make one valve act in the capacity both of a high frequency amplifier and of a low frequency or note amplifier : such is referred to as a **reflex circuit.**

In the earlier days of wireless, reflex circuits possessed a certain fascination to experimenters ; they saved a valve (a serious consideration in those days) and a single valve reflex was the loudest single valve set then in existence. In recent years, however, their popularity has waned, partly because the advent of cheaper valves and components has brought the multivalve set within the reach of all, and partly because they do not reach the standard that can be reached with other circuits : they are not so selective and " buzzing " and oscillations are common defects.

Fig. 192 depicts a simple reflex circuit employing one valve and a crystal. Here the valve first acts as a high frequency amplifying valve, the amplified signals being next rectified by the crystal. These rectified signals are then passed through the primary winding of the transformer *PS*, the secondary winding of which is connected to the grid of the valve. The valve now amplifies these rectified signals (low frequency amplification) and finally the sound is heard in the telephones.

Coil values and condenser values should be as in previous circuits. For the broadcast band $L_1$ may be a No. 35 or 50 and $L_2$ a No. 50 or 75; for Daventry $L_1$ may be a No. 150 or 200 and $L_2$ a No. 200 or 250. Suitable values for $C_1$, $C_2$, and $C_3$ are $\cdot 0005\mu F$, $\cdot 001\mu F$, and $\cdot 0003\mu F$ respectively. The transformer $PS$ should not have a big transformation ratio—not more than 3 : 1. For the best results about 100 volts high tension will be required.

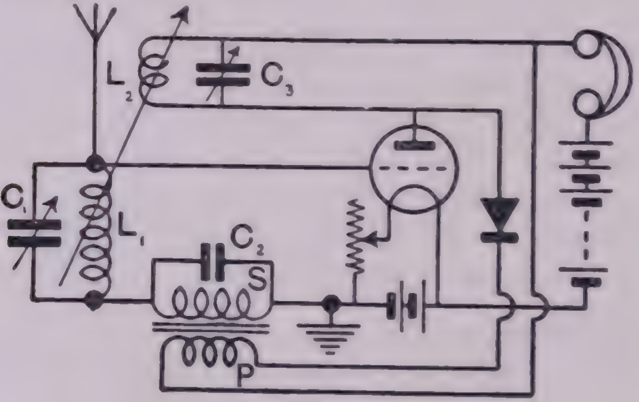


Fig. 192.

In tuning, contact is first made with the crystal, then, with $L_2$ well back, $C_1$ and $C_3$ are adjusted. The coupling between

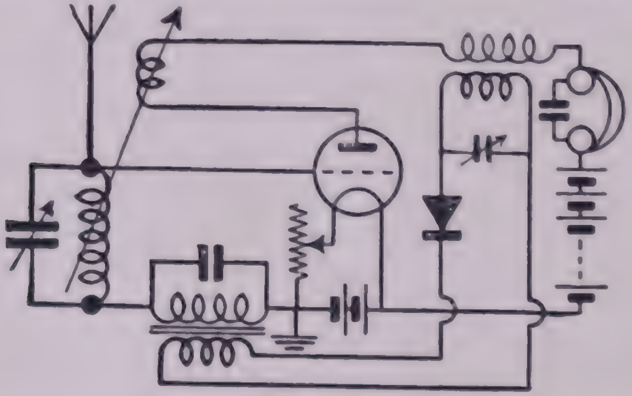


Fig. 193.

$L_1$ and $L_2$ is then adjusted, $C_1$ and $C_3$ being again slightly altered as necessary: finally the crystal is attended to.

If there is a tendency for the circuit to howl, the following should be tried in turn :—the coupling between $L_1$ and $L_2$ should be loosened : the plate voltage should be reduced : the connections of the secondary should be reversed.

Care must be taken to see that the reaction coil is connected in the right direction : if the circuit does not give increased signals when the coupling between $L_1$ and $L_2$ is increased, the connections to $L_2$ should be reversed.

A reflex circuit of this type is not so good as one with two valves and a crystal in which one valve is acting as a high frequency amplifier alone and the other as a low frequency amplifier alone, the crystal acting as a detector.

A modification of Fig. 192 is shown in Fig. 193 : this reflex circuit differs from the preceding in the sense that transformer coupling is used in the plate circuit of the valve. The diagram is self-explanatory.

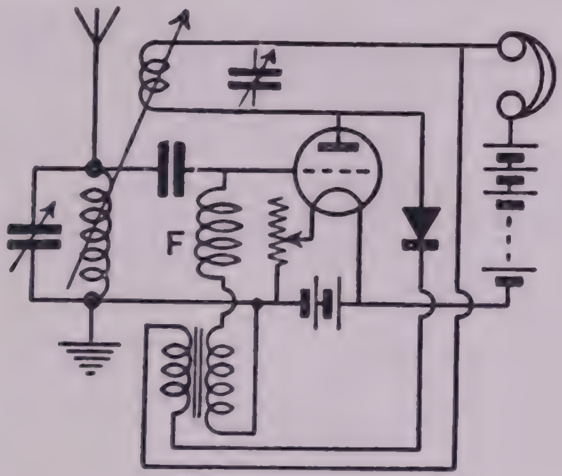


Fig. 194.

Fig. 194 gives yet another reflex circuit in which the low frequency signals produced by the crystal are fed back to the grid of the valve, via the transformer and the choke coil *F*. A convenient value for *F* for the ordinary band is a No. 200 or 250 coil. The condenser between *F* and the aerial coil should be about ·0003$\mu F$.

There are numerous other types of reflex circuits, but the principle of action is much the same in all. As already indicated, they are not altogether " popular " circuits at the present day (candidly, we ourselves, and we have worked with several, don't like them) but there are indications that their possibilities may again attract experimenters at no distant date.

**145. The Principle of the Super-sonic Heterodyne.**—The multivalve (seven or eight or more valves) "Super-Het" is scarcely a receiving set which is suitable for a beginner, and is therefore scarcely a circuit which should be described in this book. At the same time, the reader will come across references to it so often, in his general reading, that a brief note on the general principle underlying its action is desirable.

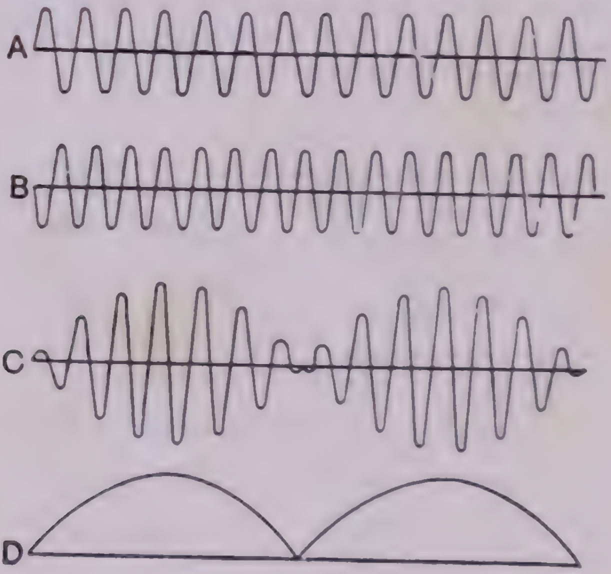


Fig. 195.

The difficulties in connection with the employment of two or more stages of high frequency amplification—the self-oscillation tendency and the control of it—have frequently been referred to in preceding pages. Further, students who have experimented with this high frequency amplification will know that the tendency to burst into oscillation is much more pronounced with short waves (higher frequency) than with long waves (lower frequency).

Now, after all, amidst all the various valves and "local oscillations" and what not in the super-het circuit, what the circuit really does is to change waves into longer waves—much longer waves—which are afterwards amplified several times if necessary, and this is done by combining the waves from a "local oscillator" with the incoming waves, thereby producing longer resultant waves as indicated in the heterodyne principle mentioned in Art. 93.

A "local oscillator" is simply a valve circuit so arranged that it produces oscillations—in fact it acts as a transmitting circuit, and the frequency of these oscillations (and the wave length) can be varied by a variable condenser.

Thus if *A* (Fig. 195) gives the waves arriving at the aerial and *B* the waves produced by the local oscillator, the two combined give *C* (Art. 93) : after rectification, the net result (as already explained) is *D*—waves much longer than either *A* or *B*.

The local oscillator is so adjusted that the resultant wave *C* is anything from 2000 metres to, say, 12,000 metres in length (super-audible frequency). This long wave can then be manipulated—more or less in the usual way—and the apparatus will be efficient in dealing with it.

The preceding gives, of course, only a very elementary idea of the working of a supersonic heterodyne, but further details are beyond the scope of this book.

# CHAPTER XIII.

## SIMPLE VALVE TRANSMITTERS: DIRECTIONAL WORK: BEAM SYSTEM: WAVE LENGTHS: TELEVISION.

**146. Valve Transmitting Sets—The Production of Undamped Oscillations and Undamped Waves by means of Valves.**—Reference was made in Chapter VII. to the production of undamped oscillations which give rise to undamped or continuous waves as used in wireless telegraphy and telephony, and certain methods of producing such oscillations and waves—arc, high frequency alternator, high frequency alternator in conjunction with frequency changing transformers—were briefly indicated. At the same time it was mentioned that such methods were to-day largely superseded by methods employing thermionic valves. A full treatment of these valve methods for the production of continuous waves as used in modern wireless transmitting stations is, of course, outside the scope of this book, but a few general ideas may be given in an elementary way. For fuller details the student should refer to *A Text Book of Wireless Telegraphy and Telephony* by W. Greenwood, B.Sc.

In dealing with reaction in previous pages it was explained that if the energy fed back from the plate circuit to the grid circuit be greater than the energy required to make up the losses in the grid circuit oscillations will be set up. Even when no energy is being received from the aerial circuit these oscillations can be maintained. (The student who has experimented with previous circuits will know this quite well. As another illustration he should recall, for example, the neutrodyne circuit: in adjusting this he gets oscillations when the aerial circuit is *not* connected to the set). All this indicates the possibility of using a valve for the production of oscillations for transmitting purposes.

The simplest arrangement for the production of undamped oscillations by means of a valve is shown in Fig. 196, the circuit *CLR* being the one in which it is desired to set up the continuous oscillations. It is connected between the plate and filament of the valve *via* the batteries as indicated. The valve is arranged to work on the steepest part of its characteristic, the battery $B_2$ being used to get the correct grid potential. The student will have no difficulty in understanding the various connections, etc.

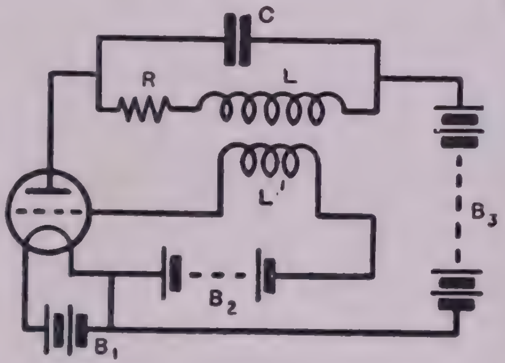


Fig. 196.

Now suppose that by some means (such as the closing of a key in the circuit of $B_3$) a small oscillatory current is set up in the circuit *CLR*. For each half cycle of this current there will be an induced E.M.F. in $L^1$, with a corresponding induced current which flows to the grid circuit, thereby varying the grid potential and producing a corresponding change in the plate current. Clearly then the oscillatory current set up in the circuit *CLR* results in corresponding changes in the plate current, and an oscillatory current of frequency equal to that of the one set up in *CLR* is superimposed on the steady plate current. This again acts inductively on $L^1$, which again varies the grid potential, again resulting in corresponding changes in the plate current and so on; thus the oscillations, once started, are maintained, *i.e.* continuous oscillations are set up in the circuit *CLR*, the circuit losses being made good by the battery $B_3$. The student should thoroughly grasp this idea before proceeding further.

The state of affairs might be represented graphically as in Fig. 197. Here *A* represents two cycles of the oscillatory current in *CLR*, whilst *B* represents the corresponding induced E.M.F. in $L^1$. The change in the plate current depends on this E.M.F., the plate current being greatest when the E.M.F. has its greatest positive value, and least when the E.M.F. has its greatest negative value: the curve of plate current may therefore be represented by *C*. It should be noted that the curves are not drawn in any way to scale.

An examination of the curves will show that the changes in the plate current through the *CLR* circuit are of exactly the right kind to maintain the oscillations in the circuit *CLR*. If the changes in the plate current are sufficiently large they will more than maintain the oscillations and the amplitude will increase, but this is limited by the maximum value of the plate current. Thus the puffs of current through *CLR* cannot exceed a certain amplitude, so that the amplitude of the oscillations they maintain is limited.

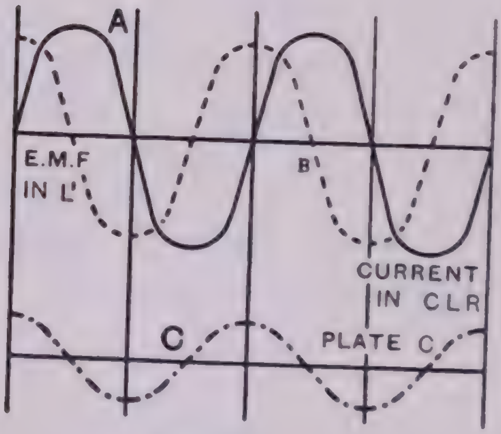


Fig. 197.

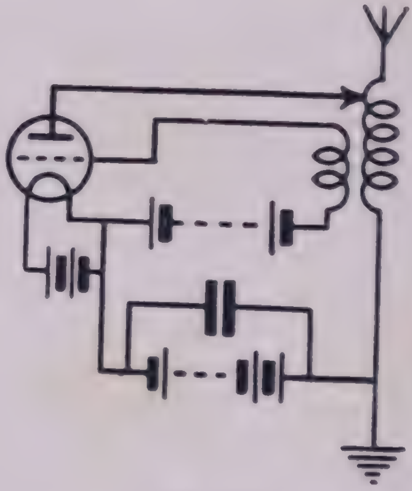


Fig. 198.

An aerial circuit may now be "coupled" to the oscillatory circuit *CLR* in the usual way, and continuous waves—wireless waves—sent out through the aether as explained in preceding chapters. Another method is to replace the *CLR* circuit by the aerial circuit itself as shown in Fig. 198 : the condenser across the battery improves matters by taking the high frequency component of the plate current. The explanation of the action is the same as before.

A slight modification is indicated in Fig. 199 : if the student compares this with the simple single valve receiver with reaction depicted in Fig. 160 he will note that the main difference is that in the transmitting circuit of Fig. 199 the aerial is put in the plate circuit and not in the grid circuit as is the case with the receiving circuit: the oscillations are greatest, of course, in the plate circuit.

In Fig. 199 there is a big potential difference between the filament and the earth, as the battery comes in between the two. To prevent this, when the plate supply voltage is high, the arrangement shown in Fig. 200 is adopted. The blocking condenser in the plate circuit prevents any short circuit from the plate supply through the aerial inductance back to the plate supply. The choke stops any high frequency current from going though the plate supply.

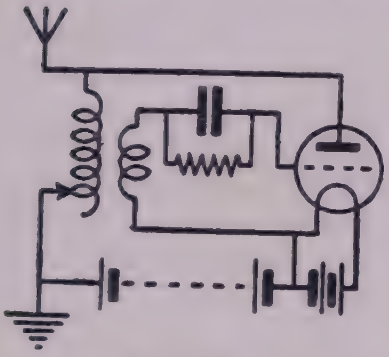


Fig. 199.

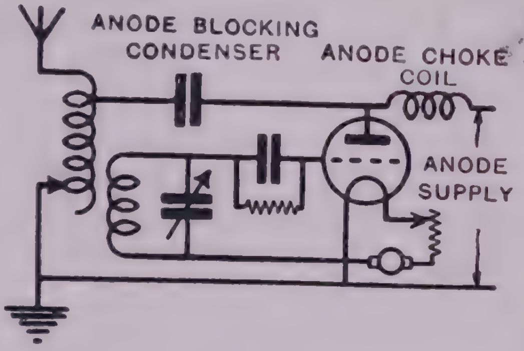


Fig. 200.

Having obtained continuous oscillations in the aerial and continuous waves emanating therefrom, the next questions arise; what about telegraphy—the sending out of the dots and dashes of the Morse code—and what about telephony—the transmission of music and speech? Well, the former is accomplished by inserting a key, say in the plate circuit of the valve, and making and breaking the plate current as explained in Chapter VII.: the latter necessitates a microphone, say in the aerial circuit, by which the waves sent out can be "modulated" as is also explained in Chapter VII. Thus we have the essentials of both wireless telegraphy and telephony.

The many steps in the development of valve transmitting sets from the comparatively simple illustrations given above to the more or less complicated appliances of the modern transmitting station are, of course, beyond the scope of this book, but the following points may be noted.

(1) In large stations several valves are necessary in order to

secure sufficient power, the valves usually being connected in parallel, although both series and parallel arrangements may be adopted.

(2) The voltage applied to the plates in modern transmitters is very high—of the order of thousands of volts. Batteries and direct current dynamos have therefore been largely superseded by rectified alternating current, *i.e.* high pressure alternating current changed into direct current. Diode valves are frequently used for rectifying purposes.

(3) The filament supply is sometimes from accumulators and sometimes from a small direct current dynamo, although alternating current is also used for the purpose. This need not be rectified for either D.C. or A.C. will serve for heating the filament.

(4) For signalling purposes—dots and dashes—the key may be in the plate circuit or the grid circuit or both circuits may be broken or closed simultaneously. Special keys which can be manipulated at a distance are necessary in high power sets.

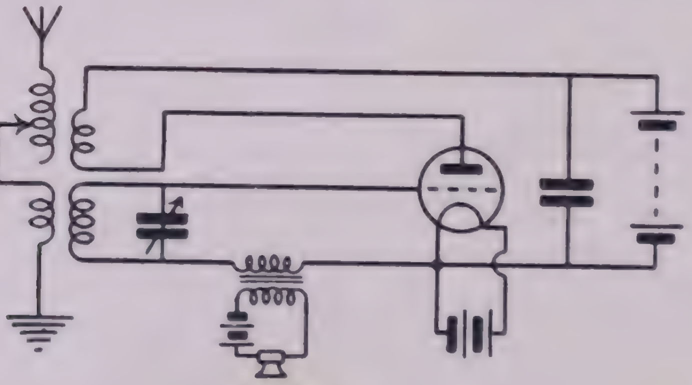


Fig. 201.

(5) For telephony—speech and music—the modulation of the waves can be brought about by placing the microphone in the aerial circuit as already indicated (Chapter VII.), and shown in principle in Fig. 104(*a*): in this case when the operator speaks, say, into the microphone, the microphone resistance is varied and this produces variations in the aerial oscillations and in the waves, according to the words spoken. The microphone may also be placed in a separate circuit which is inductively coupled with the aerial.

Another method is to vary the grid voltage as shown in Fig. 201. When the operator speaks into the microphone, the current in the microphone circuit varies. This causes a corresponding variation in the secondary of the iron core transformer : thus corresponding variations are produced in the potential of the grid, with again corresponding variations in the plate circuit, in the aerial oscillations, and in the waves.

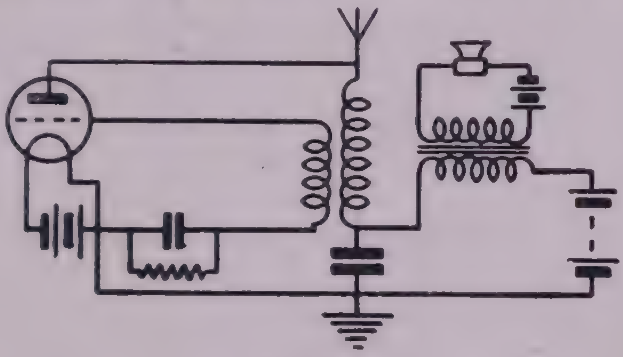


Fig. 202.

Yet another method—and the one mainly used—is to vary the plate voltage as shown in Fig. 202 : the microphone is coupled to the plate supply circuit by a transformer. When the operator speaks into the microphone, the current in the microphone varies, producing variations in the plate circuit and modulating the aerial oscillations and waves as previously indicated.

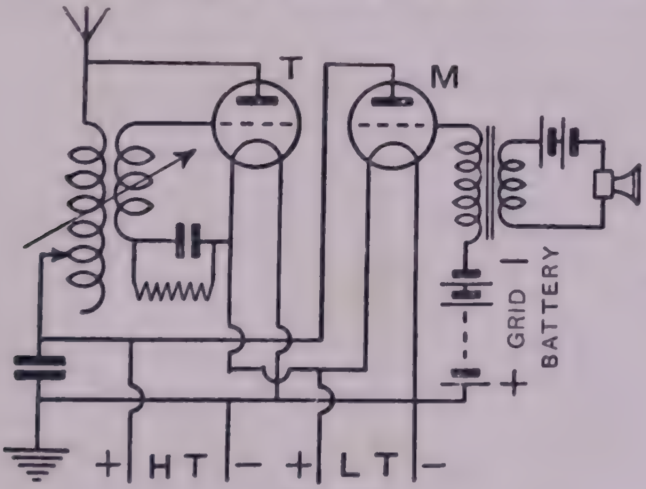


Fig. 203.

(6) In practice the microphone variations are themselves amplified by means of low frequency amplifying valves before they are applied to the plate circuit.

Fig. 203 depicts a simple telephony transmission circuit suitable for amateurs, the microphone variations being amplified by the low frequency amplifying valve *M*. *T* is the transmitting valve. The student should carefully think out the action of this circuit.

For further particulars in connection with modern valve transmitting circuits reference should be made to the book already mentioned and from which Figures 198-202 of this section have been reproduced.

**147. Directional Transmission and Reception.**—The directional reception properties of the horizontal aerial and, to a greater extent, of the frame aerial, have been dealt with in Arts. 94, 108, which the student should read again before proceeding further. Apart from these, the question of directional transmission and reception is not of vital importance to the student at this stage, although the subject is really an important one in the commercial development of wireless: the following account is therefore necessary, but designedly brief.

The first important arrangement for directional transmission which we need examine is that of MM. Bellini and Tosi. Consider an aerial consisting of a vertical triangle of wire, the vertical sides *not* connected at the top, and the base containing the aerial and earth terminals of the transmitting apparatus. From what has been said in Chapters VII. and IX. it will be clear that the radiation will be mainly *in the plane of the triangle*. If *AB* (Fig. 204) depicts the base of the triangle, the radiation will be mainly to the right or left, and in fact can be approximately represented by the two circles (we might say by a figure 8): the radiation right or left is represented by the diameter of the circle, the radiation in the direction of *r* is represented by

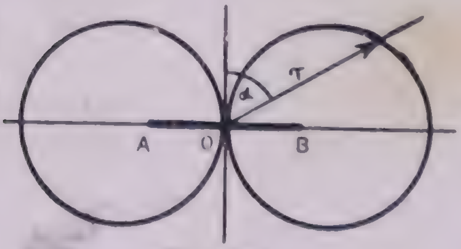


Fig. 204.

the chord $r$. the radiation at right angles to $AB$ (*i.e.* to the plane of the triangle) at $O$ is zero and so on : such a diagram when properly constructed is known as a polar diagram.

Now consider two such triangular aerials fixed at right angles to each other, with another aerial—a simple vertical aerial—at the centre of the triangles. Suppose the vertical aerial and one of the triangular aerials radiate. The triangular aerial will give the figure 8 for polar diagram, and the vertical aerial will give a circle, since it radiates equally in all directions : these are shown at $A$ and $B$ respectively (Fig. 205). The resultant of these is the curve $C$ (attention must be paid, of course, to the *direction* of the radiation in the $A$ and $B$ curves in plotting the $C$ curve) and it will be clear from this curve that the energy radiated is not only mainly in the plane of the two aerials in question, but it is also *mainly to one end.*

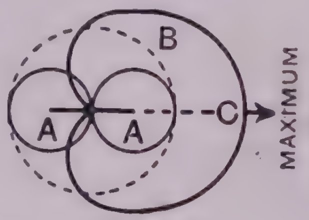


Fig. 205.

Imagine now that the vertical aerial and the other triangular aerial radiate. The result will be similar, but the $A$ curve—the 8—will be turned through 90°, and so will the resultant radiation as given by the curve $C$. These facts are the basis of the action of the Bellini-Tosi directional transmission aerial.

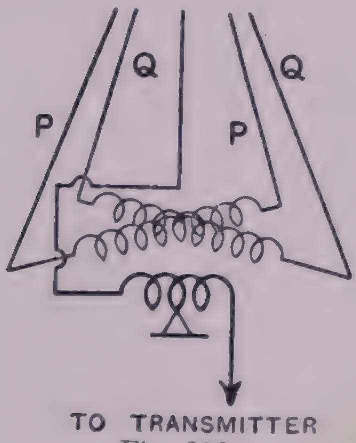


Fig. 206.

The Bellini-Tosi directional aerial for transmission is indicated *in principle* in Fig. 206. The two triangular aerials are at right angles, and the vertical aerial includes a pivoted coil in which the oscillations are set up. If this coil be placed parallel to one triangle $P$ and thus coupled with its coil, the coupling with the coil of the other triangle $Q$ will be a minimum ; hence $Q$ will not be acting at all, the radiation will be from $P$ and the vertical aerial, and the resultant will be as shown in Fig. 205. If the pivoted coil be parallel to the other triangle $Q$ and thus coupled with its coil, the coupling with $P$ will be a minimum: hence $P$ will not be acting, the radiation will be from $Q$ and the vertical aerial, and the resultant will be as shown in Fig. 205, *but moved through* 90°. For intermediate positions of the moving coil both triangles will be acting by an amount depending on their relative coupling, the direction of greatest radiation (curve $C$) being that of the pivoted coil; thus the radiation can be sent out (more or less) in any particular direction.

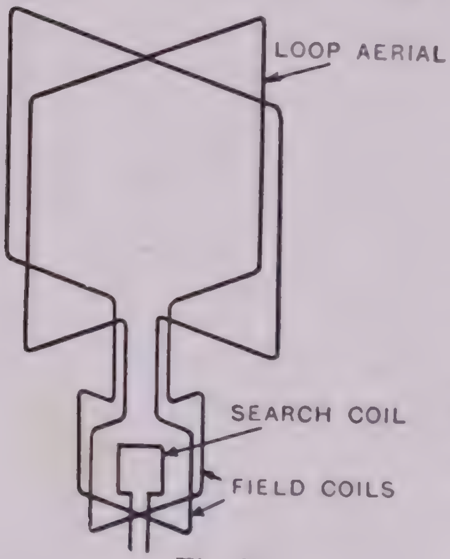


Fig. 207.

The Bellini-Tosi directional aerial for reception is shown in Fig. 207; this depicts closed loops instead of open triangles. The aerials are at right angles as before: each carries what is called a field coil, the two field coils being also at right angles. A small search coil is placed as indicated: it is pivoted and therefore capable of rotation.

Now let $P$ and $Q$ (Fig. 208) be a plan of the loops and $R$ the direction in which waves are coming. The current set up in the $P$ coil by the waves depends on the angle $a$ and therefore the magnetic field due to this current in $P$ (which field is of course at right angles to $P$, *i.e.* along $Q$) depends on the angle $a$. Similarly the current set up in the $Q$ coil depends on the angle $b$ and therefore the magnetic field due to the current in $Q$ (which field is along $P$) depends on the angle $b$. Further, it can be shown that *the resultant magnetic field is at right angles to R*. If the search coil be placed *at right angles to this resultant field* it will have the maximum number of lines passing through it, and will give the strongest signals due to the current induced in it: in other words it will give the strongest signals when it lies *in the direction in which the waves are coming*, i.e. in the direction of $R$.

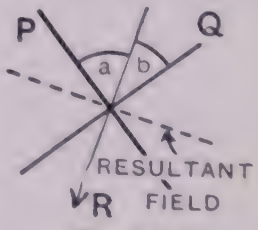


Fig. 208.

Clearly the greatest current will be set up in the aerial *P* when it lies along the direction of *R* (in which case there is no current in *Q*) and the greatest current will be set up in the aerial *Q* when it lies along *R* (in which case there is no current in *P*).

A directional reception system known as the Robinson system is used in the Royal Air Force. It consists of two coils *A* and *B* fixed at right angles but capable of rotation about a vertical axis. The two coils are in series, but the connections of one—say coil *A*—can be reversed. When *A* is at right angles to the direction in which the waves are coming, no E.M.F. will be induced in it, and therefore there will be no alteration in the strength of the signals received by the other coil—*i.e.* *B*—when the reversing switch connected to *A* is worked. When this occurs, then *B* is pointing in the direction of the waves and *A* at right angles to them.

A somewhat similar arrangement is used by the R.A.F. for directional transmission.

There are other methods of directional transmission and reception of the waves at present employed in wireless, and probably important advances will be made in the near future, but the above general principles are sufficient for the student at this stage.

We have purposely refrained from saying much on this subject of directional work in wireless, partly because it is not a matter of great interest to a beginner, but mainly because future developments in this direction will probably fall within the domain of short wave wireless as distinct from the long wave wireless of to-day. Non-directional transmitting stations which throw their waves in all directions will, of course, always be necessary for many purposes, *e.g.* for broadcasting, for ships at sea, for certain naval and military purposes, etc., but for many commercial purposes it seems most desirable to be able to concentrate the whole of the radiant energy into a beam directed towards a definite locality with which it is desired to communicate. If London wishes to communicate on some business or political or friendly subject with New York there is no good reason why Germany and Russia should know all about it. The question of directional transmission (and reception) therefore is one which must seriously engage the attention of the wireless engineer, and, as mentioned, the best solution is bound up with the question of short wave transmission—the "beam" system in which the short waves can be thrown out by an arrangement of reflectors just as the beam of light waves from a searchlight is thrown out in one direction by means of reflectors. A few particulars of the latest beam system are given in Art. 148.

**148. Short Wave Wireless Telegraphy. The Beam System.**—A little consideration will convince the reader that the aether may be becoming, as it were, somewhat congested with radio waves *of certain frequencies* (and, therefore, wave lengths), and it will be readily understood that if aether waves are to be utilised to the utmost—for commercial telegraphy and telephony, for controlling mechanisms such as targets, aeroplanes, torpedoes at a distance, for transmitting electric power—it will be very necessary to increase the range of available frequencies. And, moreover, for telegraphy and many commercial purposes it is clear that it would be very desirable to be able to project the waves in the required direction only so as to reduce the loss due to that spreading out of the energy into space (which spreading out is, of course, necessary for broadcasting and certain other purposes), and, in cases, to secure that greater "secrecy" in communication already referred to.

Until comparatively recently wireless telegraph engineers considered it necessary, for long distance communication, to use "long" waves with, of course, the consequent large and expensive aerial systems and very large amounts of power. Wave lengths between 8,000 and 30,000 metres (*i.e.* frequencies of, say, 37 to 10 kilocycles per second) have been practically exclusively employed in commercial wireless telegraphy: the new high-power station at Rugby, which is a "world-wide" station, uses waves of 1875 metres (16 kilocycles per second) and the power employed is about 1,400 kilowatts.

During recent years, however, many experiments have been made with short waves, *i.e.* very high frequency waves, both by amateurs and by radio engineers, considerable improvements have been effected in the matter of both their production and detection, and Senatore Marconi has definitely shown that they can be used satisfactorily for commercial long-distance telegraphy, the daylight range steadily increasing as the wave length is decreased. As compared with long waves the capital expenditure on aerials and plant is much less, for smaller aerials and less power are necessary: the running costs and maintenance costs are lower: the speed of signalling—the rate at which the dots and dashes of the Morse Code can be transmitted—is much greater: interference from atmospherics is said to be less: and the short waves can be reflected towards a definite direction, thus concentrating the energy in the direction in which it is required and increasing signal strength. It is, of course, this latter property which has given the name of "the beam system" to the latest scheme of short wave wireless telegraphy established by Senatore Marconi.

The Government in 1923 decided to proceed with the erection of wireless stations to communicate with each of the Dominions, the contract being placed with the Marconi Company. At a later date, in consequence of the results of the experiments referred to above on short waves projected in the form of a beam by reflectors, it was agreed that these should be short wave beam stations designed to communicate with Canada, South Africa, Australia, and India, corresponding stations being erected in these Dominions, and the building of the stations was commenced in April, 1925. With the long wave high power world-wide station at Rugby and these short wave lower power beam stations, Great Britain will have the most complete wireless service in existence..

The first beam stations were opened officially on Monday, October 25th, 1926, for communication with Canada. The station for transmitting to Canada is situated at Bodmin, and the station for receiving from Canada is near Bridgwater. The corresponding transmitting station in Canada is at Drummondville, 30 miles north-east of Montreal, and the receiving station is at Yamachiche to the north of Drummondville. The English stations are linked up by land lines to the General Post Office, London, and the Canadian stations by land lines to the central office in Montreal. The Bodmin station also comprises a second transmitting system for communication with South Africa, and the Bridgwater station a system for receiving from South Africa, the corresponding South African stations being near Cape Town. Similar stations are being built at Tetney, near Grimsby, and at Winthorpe, near Skegness, for communication with Australia and India, the corresponding stations being near Melbourne and Bombay.

The masts and aerial system are similar at both sending and receiving stations, but are quite different in construction and appearance from those used in long wave wireless stations. There are five steel lattice masts for each service arranged in a straight line, this line of masts being as it were "broadside on" to the direction of the distant station. The masts are 277 feet high with cross arms at the top about 90 feet long. The aerial system consists of a number of vertical wires, somewhat like a wire curtain, suspended from a steel cable attached to the cross arms and running along one side of the row of masts. The reflecting system consists of a similar set of vertical wires suspended from a steel cable attached to the other end of the cross arms. The aerial system is on the side of the masts facing the distant station. Thus, by this aerial and reflecting device the "beam" is accurately projected in the direction of the receiving station, thus reducing loss of energy and increasing signal strength, and similarly at the receiving station energy is reflected on to the aerial, again increasing signal strength.

The wave length employed is about 100 metres, and the transmitting power only about 20 kilowatts. Counting every hour of the seven days' official test at Bodmin the average speed of signalling was about 600 letters per minute in each direction or 1,200 letters per minute for the complete circuit; for several hours per day, however, the speed was very much greater—of the order 2,500 letters per minute for the complete circuit.

Despite the wonderful progress which has thus been made quite recently in short wave transmission and reception its further study and improvement will occupy the attention of radio engineers for some time to come, and hence students should be constantly on the look out for developments in this direction.

**149. Wave-lengths in Broadcasting.**—The ever-increasing popularity of broadcast wireless telephony has caused wireless engineers to face the fact that there are now more broadcasting stations in this country and on the continent than can be given exclusive wave-length positions and assured freedom from interference with each other. To meet this difficulty an international conference was held at Geneva, and a detailed schedule of new wave-lengths to be employed was issued, the scheme being put into operation in November, 1926.

Broadcasting stations were placed in two categories:—(*a*) stations of such importance that they should be given every possibility of clear reception at a considerable distance; (*b*) stations of purely local importance for which good local reception only can be guaranteed. Eighty-three wave-lengths, known as *exclusive wave-lengths*, were set apart for category (*a*), each country in Europe being assured at least one exclusive wave-length: Great Britain was given eight exclusive wave-lengths, but decided to use one of these (491·8) for two of her main stations. Sixteen wave-lengths, known as *commune wave-lengths*, were set apart for category (*b*), *i.e.* stations of local importance: most of the British relay stations, for example, were allotted the wave-length 288·5 metres. This latter practice of putting widely separated stations of comparatively small power on the same wave-length is the outcome of recent experiments, and has been shown to be quite a success, providing each station remains perfectly steady on the wave-length assigned to it.

Crystal users are chiefly concerned with reception from the local station. In most cases the change will scarcely be noticed, but in the case of a few stations it may be necessary to make a slight alteration to the tuning arrangement, *i.e.* in either the inductance or the capacity, or both, according to circumstances. As already indicated, using a slightly larger coil will enable the set to respond to longer waves, whilst using a slightly smaller coil will bring in a shorter wave: the wave-length range is increased when a condenser is put in parallel, *i.e.* between the aerial and earth terminals; it is decreased by inserting a condenser in series, *i.e.* in the aerial lead. In most cases valve sets are provided with such a margin that no difficulty will be experienced in tuning in.

LIBRARY
B'lore-42
Accession No; 1705.
U.D.C No: 538/5
Date; 5-7-81

An interesting situation arises in the case of those listeners living about mid-way between two relay stations working on the same wave-length. If the two stations are transmitting the same programme then, theoretically, reception should be somewhat improved, but if they are transmitting different programmes the listener may hear both.

A further interesting point is the type of condenser which is most suitable for the easy and perfect tuning in of various stations on the new scheme, for the new system is really based upon frequencies rather than upon wave-lengths. (It is for this reason that such wave-lengths as 394·7, 588·2, etc., appear.) Every broadcast transmission of speech, music, etc., is accompanied by "sidebands," *i.e.* waves just a little above or a little below the normal wave-length of the station, so that every transmission really takes place not on one sharply defined wave-length, but on a band of wave-lengths. Experience shows, however, that although transmission is on a band of wave-lengths, two stations will not interfere with each other if the frequencies of their carrier waves differ from one another by 10 kilocycles or 10,000 cycles per second.

Now Stettin and Gleiwitz, for example, differ in frequency by 10 kilocycles per second, and the wave-length difference is 2·1 metres, whilst higher in the scale Munich and Sundsvall also differ in frequency by 10 kilocycles per second, but the wave-length difference is 10·9 metres. With the modern square law condenser (*i.e.* straight line wave-length condenser) the difference in the setting between Stettin and Gleiwitz will be small, whilst quite a gap will exist between the settings of Munich and Sundsvall. The square law condenser is, of course, as already indicated, a decided improvement on the older plain type, but it is evident that with the new scheme a still more suitable condenser will be a *straight line frequency condenser*, which will give, as its settings are varied, an almost perfect spacing of frequencies, so that there will be no crowding of stations at either end of the scale.

The construction of this new type of condenser which the new wave-length scheme will call into extensive use is somewhat similar to that of the straight line wave-length condenser of Chapter V., and details may be consulted in the manufacturers' catalogues.

**150. Amplification Ratio and Amplification Factor of a Valve.**—We have seen that a change in the voltage applied to the grid of a valve immediately produces a change in the plate current. A change in the plate voltage itself would, of course, also produce a change in the plate current. A certain change in the grid voltage, however, would, in most cases, produce a bigger change in the plate current than an equal change in the plate voltage would produce. The **amplification ratio** is obtained by dividing the change in plate volts necessary to produce a certain change in plate current by the change in grid volts necessary to produce the same change in plate current: thus if an increase of 20 volts applied to the plate circuit produces a change of say, ·4 milliampere in the plate current, and a change of 2½ volts in grid potential also produces ·4 milliampere change in plate current, the amplification ratio of the valve would be $\frac{20}{4\frac{1}{2}} = 8$. The measurements are supposed to be taken on the straight part of the curve. *This amplification ratio is very often erroneously called the amplification factor.*

The **amplification factor** is strictly the ratio of the power, voltage, or current available at the output terminals to the power, voltage, or current at the input terminals under certain specified conditions such as given output or given input. If $R_1$ be the external impedance in the plate circuit, and $R_2$ the internal impedance of the valve (plate to filament) it can be shown that:—

$$\text{Amplification factor} = \frac{R_1}{\sqrt{R_1^2 + R_2^2}} \times \text{Amplification ratio.}$$

**151. Television (or Teleoptics).**—It is certain that the next great development in wireless will be the successful establishment of **television**, whereby it will be possible to see, on a screen in our own homes, the speakers and singers, and performers in plays and operas, as well as to hear them: as a matter of fact wireless television is considerably nearer at hand than most people realise.

Wireless receiving sets have already reached a high standard and further developments will probably be concerned mainly with the perfection of high frequency amplification (by the extension of neutrodyne or neutralising circuits), and with the improvement of selectivity, and loud speaker reproduction. On the transmitting side it seems probable that high power stations and the present long waves will continue, whilst at the same time wonderful developments may be expected, particularly in the domain of telegraphy, with short wave transmission, the beam system, and directional work. But television is perhaps the most wonderful, and the most fascinating development which the very near future will witness.

The analogous problem of sending photographs and pictures by line or by radio or by both methods (telephotography) has been successfully solved and is now employed every day commercially. One method is briefly as follows :—

A photograph is taken on an ordinary photographic film which is developed in the usual way, and the negative clamped to a glass cylinder capable of rotation. Inside the cylinder is an electric lamp, from which a fine pencil of light is directed on to the film. As the cylinder rotates the pencil of light penetrates the light and dark parts of the film in varying degree, so that the transmitted light varies in intensity. By means of a lens this varying transmitted light is focussed on to what is called a photo-electric cell, the resistance of which, and therefore the current through which, changes according to the intensity of the light falling on it. By moving the cell along the cylinder, one step for each revolution, the whole picture is caused to operate. These varying current impulses are then amplified, after which they are caused to modulate the carrier wave from a wireless transmitting apparatus in the usual way. Thus a modulated aether wave passes out which depends upon a picture instead of upon words spoken.

At the receiving station the reverse operation takes place. The procedure is first just the same as in ordinary wireless reception. After sufficient amplification the varying current impulses (which of course correspond to the varying current impulses at the transmitting station) are caused to vary the intensity of a pencil of light from a lamp, and this varying light is caused to affect a photographic film. As the reception cylinder rotates in the same way and at the same speed as the transmission cylinder, a faithful copy of the photograph at the transmitting station is obtained on the film at the receiving station.

It is clear that in picture transmission a certain time is required for the whole picture to be traversed and transmitted—roughly about eight minutes for an average sized newspaper picture.

Television, however,—the seeing of say a speaker on a screen at the same time as the hearing of him, say on the telephones—is a much more interesting subject and a much more complicated problem than picture transmission outlined above, although the general principle follows on much the same lines. That is the image of the person to be seen is made to traverse the cell, which, as indicated above, is sensitive to light, and the cell modifies or modulates a current, the latter being large when the light on the cell is strong and small when the cell is in shadow. At the receiver the corresponding varying current controls a source of light which falls on a ground glass screen moving in step with the transmitter. The light on the screen is bright when the light at the transmitter is strong and dark when the light at the transmitter is weak. The light moves over the screen about ten times per second, so that, owing to persistence of vision, a complete image is obtained.

Many experimenters are working on these lines towards perfection in television—Mr. C. F. Jenkins in America, Prof. E. Belin in France, Mr. J. L. Baird and Capt. Hutchinson in England—and in a recent demonstration by Baird and Hutchinson in London, the successful transmission of living human faces was witnessed by many, the transmitter being in a room at the top of the building : all movements of the head, of the lips and mouth, of a cigarette and its smoke were faithfully depicted on the screen. These two investigators are already making arrangements for the establishment of a broadcast system of television in London.

Thus television, as already stated, is nearer at hand than many people realise : in two years or less the system will probably be in daily use. Further, we do not anticipate any revolutionary change in receiving apparatus in order to accommodate the new development—the "televisor" of the near future will probably be a mere attachment, and not an expensive attachment, to an existing wireless set.

No branch of science has yet reached the limits of its resources and never will, and of all the branches of science, wireless—the application of those high frequency currents which, as it were, leave their conductors behind, the utilisation of the free and untrammelled universal aether—presents perhaps the greatest possibilities. In this connection the question arises will television end at our seeing the performers at a broadcasting station to which we are tuned in, or will we attain the wireless of the day when any person will be able to reach any other person on the globe and not only speak to him but see him? The picture seems almost dramatic and imaginary, but it is nevertheless scientifically imaginary.

And time alone will show.

# INDEX.

ACCEPTOR circuits, 195
Accumulator, 50
  ,, , capacity of, 53
  ,, , care and management of, 52
  ,, charging, 50, 55
  ,, , Chloride, 57
  ,, , discharge rate, 53, 54
  ,, , energy efficiency of, 55
  ,, E.P.S., 56
  ,, Exide, 59
  ,, , ignition capacity, 54
  ,, , quantity efficiency, 55
  ,, recharging, 55
  ,, , types of, 56
Aerials, 71, 111, 152
  ,, , balanced, 158
  ,, , capacity formulae, 248
  ,, , capacity of, 71
  ,, , directional, 132, 160, Chap. XIII.
  ,, , down lead for, 156
  ,, frame, 132, 159
  ,, , horizontal, 132
  ,, , indoor, 159
  ,, , insulation of, 155
  ,, , L. type, 153
  ,, , multiple, 162
  ,, , receiving, 131
  ,, , sausage, 162
  ,, , transmitting, 130
  ,, , T. type, 153
  ,, , twin, 154
  ,, , umbrella, 163
  ,, , vertical, 132
Aerial screen, 164
Aether, 18, 105
  ,, , electric strains in, 19
  ,, , magnetic strains in, 29
  ,, strains, electric, in wireless, 30
  ,, strains, magnetic, in wireless, 30
Alternating currents, 87
  ,, ,, , choking effect of inductance on, 92
  ,, ,, flow through a condenser, 91
  ,, ,, , measurement of, 90
  ,, pressures, 87
  ,, ,, , measurement of, 90
Alternators, high frequency for continuous wave production, 126
Aluminium, 8
Amalgamation, 45
Ammeter, 35
Ampere, 34
  ,, hour, 35
  ,, , virtual, 90
Amplification by valves, 175-179, 201, Chap. XII.
  ,, factor of a valve, 251
  ,, ratio of a valve, 251
Amplitude, 88
Anode, 34, 51, 139
Arc, used for producing continuous waves, 122
Atmospherics, 133
Atom, 4

Attraction between magnetic poles, 21
Audio frequency, 97
„ „ amplification, 175-179, 201, Chap. XII.
Auto-transformer, 96

BACK, E.M.F., 45
Batteries, current calculation, 47
„ , filament, 52
„ , parallel grouping, 47
„ , series grouping, 47
Battery, 45
„ , grid biasing, 49
„ , high tension, 48
„ , low tension, 50
Beam system, 136, 248
Bell magneto telephone, 82
"Blocking" condenser, 71
Board of Trade Standards Committee, 35
„ „ unit, 42
Branley, 112
Brass, 8
Bright emitter valves, 140
"By pass" condenser, 71, 119

CAPACITIES, joining in parallel, 64
„ , „ „ series, 65
Capacity, 60, 85, 107
„ , electrical, 41
„ expressed in terms of length, 63
„ , formulae : condensers, 248
„ , „ aerial, 248
„ of a condenser, 63
„ of an accumulator, 53
„ , unit of, 41, 63
Carrier wave, 125
Cell, dry, 46
„ , E.C.C. dry, 46
„ , galvanic, 44
„ , Hellesen dry, 47
„ , Leclanché, 46
„ , secondary, 50
„ , simple, 44
„ , storage, 50
Charge, electric, 1
Charges, negative, 2
„ , of electricity, 2
„ , positive, 2
Charging accumulators, 50, 55
Chemical effects of a current, 33
Chloride accumulators, 57
Choke-capacity coupling, 207, etc.
„ coils, 92
Circuit, electric, properties of, 85
Closed oscillatory circuit, 109
Coatings of a condenser, 61
Coherer, 112
Coil, inductance formulae, 249
Coil windings, 79
Composition, moulded, 9
Condenser, 60
„ , "blocking," 71
„ , by-pass, 71, 119
„ , capacity formulae, 248
„ , „ of, 63
„ , discharge of, 66
„ , fixed, 68
„ grid, 71
„ , oscillatory discharge of, 66, 75. 105
„ , square law, 69
„ . variable, 68
„ , vernier, 71
Condensers, joining in parallel, 64
„ , „ „ series, 65
Conductor, 6
Conductors—
Arrangement in parallel, 39
„ series, 38
In parallel, divison of current among, 39
Used in wireless, 8
Coulomb, 35
Continuous current, 87
„ waves, 121
„ „ , methods of producing, 121, 122. 126, Chap. XIII.
Conventional current, 15
Copper, 8
Copper sulphate, electrolysis of, 34
Counterpoise, 158
Coupling, 115
„ , loose, 116, etc.
„ , tight, 116

Coupling valves, 207
Crystal detector, 113, 119, Chap. VIII.
Crystal receiving sets—Chap. X.
  Amplifiers other than valves for, 181
  Fixed coil, 170
  Increasing range of, 177
    „ signal strength of, 175
    „ „ „ and range of, 179
  Modern tendencies in, 171
  Tapped inductance, 168
  Variometer, 167
Current, chemical effects of, 33
  „ , conventional, 15
  „ , effects of, 32
  „ , electronic, 15
  „ , heating effect of, 33
  „ , magnetic effects of, 33
  „ , of electricity, 15
  „ strength, 33
  „ , unit of, 34

DAMPED oscillations, 106, etc.
  „ waves, 106, etc.
Detector, 119
  „ , crystal, 113, 119, Chaps. VIII., X.
  „ , electrolytic, 113
  „ , magnetic, 113
  „ , valve, 113, Chaps. VIII., XI., XII.
Dielectric, 10, 61
  „ , constant, 10, 64
Directional transmission and reception, 132, 159, 244
Discharge, rate of accumulator, 53, 54
Dry cell, 46
  „ , E.C.C., 46
  „ , Hellesen, 47
Dry cells in wireless, 48
Dull-emitter valve, 50

EARLY experiments in wireless, 109
Earth systems, 157, 162
Ebonite, 9
E.C.C. dry cell, 46
Eddy currents, 95, 102
Electric aether strains in wireless, 30
Electric charge, 1
  „ circuit, properties of, 85
  „ field, 16
  „ lines of force, 16
  „ strains in aether, 19, 107
  „ strain lines in aether, 19, 30, 128
Electrical potential, 11, 12
  „ „ , analogy to air pressure, 11
  „ „ , analogy to air temperature, 11
  „ „ , analogy to water level, 11
  „ pressure, 9
  „ tension, 12
  „ units, 32
Electricity, 1
  „ , charges of, 2
Electrification, 1
  „ , two states of, 1
Electrodes, 34
Electrolysis, 34
Electrolyte, 34
Electrolytic detector, 113
Electromagnetic waves, Chap. VII. etc.
  „ „ , table of, 135
Electromagnets, 20
  „ , 28
Electromotive force, unit of, 36
Electron, 4, etc.
  „ theory, the, 4, 7
  „ „ , applied to discharge of a condenser, 62
Electronic current, 15
Electrostatic induction, 9, 14
Energy, efficiency of an accumulator, 55
  „ , electrical, 41
  „ transformation, 41

E.P.S. accumulators, 56
Exide battery, 59

FADING, 134
Farad, 41, 63
Faraday, 18, 24, 71
Faure, 51, 52
Fessenden, 124
Field, electric, 16
,, , magnetic, 23
Filament batteries, 52
Fixed condenser, 68
Flow of electricity, 15
Foucault currents, 95
“Forming” accumulator plates, 51
Franklin, 2
Frequency, 88, 104, 167, etc.
,, , changing transformer, 126
,, , note, 114
,, . spark, 114
,, , wireless, 114

GALVANIC cell, 44
Galvanometer, 35
Grid biasing battery, 49
,, condenser, 71

HEAT, effect on resistance, 41
Heating effect of a current, 33
Heaviside layer, 131
Hellesen dry cell, 47
Henry, the, 75
Hertz, 109, 112, 135
,, detector, 110
,, oscillator, 110
Heterodyne, 124
,, , supersonic, 235
High frequency oscillatory current, 89, etc.
,, ,, transformer, 97
,, ,, ,, McMichael, 97
High potential plate of cell, 44
High tension battery, 48
Horse-power, relation to kilowatt, 43
Hydrometer, 54
Hysteresis, 95

“IGNITION capacity” of accumulator, 54
Impedance, 98
Induced current, 71
,, E.M.F., 71
Inductance, 75, 85, 107
,, basket, 79
,, , choking effect of, 92
,, coil, plug-in, 79
,, coils, 76
,, expressed in terms of length, 75
,, formulae, 249
,, lattice, 79
,, , loose coupler, 77
,, , pile wound, 78
,, , sliding, 77
,, tapped, 77
,, , unit of, 75
,, , vario-coupler, 78
Induction coil, 81
,, , electrostatic, 9, 14
,, , magnetic, 21
,, , mutual, 72
,, of currents by magnets, 72
,, , self, 73
Inductive displacement, 61
Inertia, 74
Insulator, 6
Insulators, used in wireless, 8
Ion, 6
,, , negative, 6
,, , positive, 6
Ions, 34
Ionisation of atmosphere, 131
Iron ore, magnetic, 20

JACKSON, Admiral Sir H., 135

KATHODE, 34, 51
Kilowatt, 43
,, , relation to horse-power, 43

LAGGING currents, 89
Law of induced polarity, 22
Laws of resistance, 40
Leading current, 89
Leclanché cell, 46
Lenz's Law, 72

Light waves, relation to wireless waves, 134
Lines of electric force, 16
  ,, force, magnetic, 23
Local action, 45
Lodge, Sir Oliver, 19, 112, 135
Loose coupler inductance, 77
  ,, coupling, 116
Loud speaker, 84
Low potential plate of cell, 44
  ,, tension battery, 50
  ,, frequency transformer, 97
  ,, ,, ,, , R.I., 97
Luminiferous aether, 18

MAGNETIC aether strains in wireless, 30
  ,, detector, 113
  ,, effects of a current, 33
  ,, field, 23
  ,, ,, due to current in a solenoid, 27
  ,, ,, ,, ,, current in circular coil of wire, 27
  ,, ,, ,, ,, current in straight wire, 25
  ,, ,, ,, ,, parallel currents, 29
  ,, induction, 21
  ,, lines of force, 23
  ,, strains in aether, 29, 107
  ,, strain lines in aether, 128
Magnetism, 20
Magnetite, 20
Magnets, 20
  ,, , artificial, 20
  ,, , natural, 20
  ,, , permanent, 20
Marconi, 111, 135, 136
Marconi's first receiving circuit, 113
  ,, ,, transmitting circuit, 111, 112

Matt ebonite, 9
  ,, finish, 9
Matting, 9
McMichael high frequency transformer, 97
Megger, 36
Megohm, 36
Mica, 8
Micanite cloth, 8
  ,, paper, 8
Microfarad, 63
Microhenry, 75
Microhm, 36
Micro-micro-farad, 63
Microphone, 82, 84
Morse Code, 112, 114
Mutual induction, 72

NEGATIVE charges, 2
  ,, plate of cell, 51
  ,, pole of a cell, 45
Neutral bodies, 1
Neutrodyne, circuits, 218, 230, 232
Neutrodyning, 217
Note frequency, 114

OHM, 35, 36
Ohmmeter, 36
Ohm's Law, 37
"One fluid" theory, 2
  ,, ,, ,, , the modified, 6
Open circuit, 37
  ,, oscillatory circuit, 109
Oscillation, 103
Oscillations, with high frequency valves, 217
Oscillatory circuit, 107
  ,, ,, closed, 109
  ,, ,, open, 109
  ,, current, 102
  ,, ,, , high frequency, 89
  ,, ,, , undamped, 121
  ,, discharge, 67
  ,, , of a condenser, 66, 75, 105

PARAFFIN wax, 8
Parallel arrangement of condensers, 64
,, ,, ,, conductors, 39
,, feed circuits, 221
,, , feed coupling, 207
,, grouping of batteries, 48
,, resonance, 101
Period, 88
Periodic time, 104
Permanent magnets, 20
Phase difference, 90
Pile wound inductances, 78
Planté, 51, 52
Plate of cell, high potential, 44
,, ,, ,, , low potential, 44
,, ,, ,, , negative, 51
,, ,, ,, , positive, 51
Plug-in inductance coil, 79
Polarisation, 45, 49
Poles of a cell, 44
,, ,, magnet, 20, 21
Positive charges, 2
,, plate of cell, 51
,, pole of cell, 44
Potential difference, 14
,, ,, , unit of, 36
,, , electrical, 11, 12
,, of the earth, 13
Poulsen, 122
Power, electrical, 42
Pressure of electricity, 3
Primary circuit, 72
Propagation of " wireless " waves, 128
Proton, 4

QUANTITY efficiency of an accumulator, 55
,, of electricity, 33
,, , units of, 35
Quenched spark gap system, 116

RADION mahoganite, 9
Reactance, 99
Reaction, 184
Reception, directional, 132, 159, 244
Recharging accumulators, 55
Rectifier, 119, etc.
Reflex circuits, 201, 233
Rejector circuits, 195
Relativity, theory of, 19
Repulsion between magnetic poles, 21
Resistance, 35, 36, 85, 98, 107
,, , effect of heat on, 41
,, , laws of, 40
,, of an alloy, 40
,, , unit of, 35
Resonance, 100, 104, 111
,, , parallel, 101
,, , series, 101
Resistance-capacity coupling, 207
Resistivity, 40
R.I. low frequency transformer, 97
R.M.S. values, 90
Root mean square values, 90
Rotary spark gap, 116
Rotor, 76

SECONDARY cell, 50
,, circuit, 72
Selectivity, 153
Self induction, 73
Sellon-Volckmar plates, 52
Series arrangement of condensers, 65
,, ,, ,, conductors, 38
,, grouping of batteries, 47
,, resonance, 101
Shellac, 8
,, varnish, 8
Short " wireless " waves, 135
Silver nitrate, 34, 35
Simple cell, 44
Sliding inductance, 77
Solenoid, 27
Sound waves, 103
Spark frequency, 114
Specific gravity of accumulator acid, 54
,, inductive capacity, 10, 64
,, resistance, 40
Square law condenser, 69
Standards Committee of the Board of Trade, 35
States of electrification, 1
Stator, 76

Storage cell, 50
Strain, lines, electric, in aether, 19, 107, 128
,, , magnetic in aether, 30, 107, 128
Strains, electric, in aether, 19, etc.
,, , magnetic in aether, 29, etc.
Stranded wire, 40
"Strays," 86
Sulphating, 54
Super-sonic Heterodyne, 235
Symmer, 2

TAPPED inductance, 77
Telephone, 82
Telephony, principle of wireless, 124
Telephotography, 252
Television, 251
Tension, electrical, 12
Theory of relativity, 19
Tight coupling, 116
Transformation of energy, 41
Transformer, closed magnetic circuit, 96
,, , core type, 96
,, coupling, 207
,, , frequency changing, 126
,, , high frequency, 97
,, , low frequency, 97
,, , McMichael high frequency, 97
,, , open magnetic circuit, 96
,, , R.I. low frequency, 97
,, , shell type, 96
Transformers, 93
,, , iron core, 75
,, , step down, 84, 94
,, , step up, 94
Transmission, Directional, 244
,, of "wireless" waves, conditions favourable to, 133
Transmitters, Chapt. VII.
,, , valve, 238-244
Tuned anode coupling, 207
Tuning, 69, 111, 118

UNDAMPED oscillatory currents, 121
,, waves, 121
Unit, Board of Trade, 42
,, of capacity, 41, 63
,, of current strength, 34
., of electrical energy, 42
,, of electromotive force, 36
,, of inductance, 75
,, of potential difference, 36
,, of quantity, 35
,, of resistance, 35
Units, electrical, 32

VALVE, amplifier, 143
,, , bright emitter, 140
,, , characteristic curves of, 141, 150
,, detector, 113, 144
,, diode, 139
,, , dull emitter, 50, 140, 149
,, , table of particulars of, 151
,, , triode, 140
,, , uses of, 142
,, , various types of, 147
Valve, receiving sets and circuits—Chaps. XI., XII.
Armstrong regenerative single, 200
Coupling amplifiers in, 207
Flewelling regenerative single, 199
High frequency amplifiers in, 177, 201, Chap. XII.
Loose coupled single, 189
,, ,, ,, , with split secondary reaction, 191
Low frequency amplifiers in, 175, 201, Chap. XII.
Modifications in single, 188
Reflex, 201, Chap. XII.
Reinartz single, 192
Single, with reaction, 187
Super regenerative single, 198
Three, 222-227
Two (Dct. and L.F.), 208,213
Two (H.F. and Dct.), 213-221

Valve, receiving sets and circuits (*continued*)—
  Wave trap single, 197
  ,, traps with, 194
  With more than three valves, 228
Valve transmitting sets, 238-244
Variable condenser, 68
Vario-coupler inductance, 78
Variometer, 76
Varnish, shellac, 8
Velocity of sound waves, 104
Vernier condenser, 71
Vibration, 103
Virtual amperes, 90
  ,, volts, 90
Volt, 36
Voltameter, 34, 37, 49
Volts, virtual, 90

WANDER plugs, 49
Watt, 43
Watt-hour, 42
Wave length, 60, 69, 103, 251
  ,, motion, 31
  ,, trap, 102, 194
Waves, electromagnetic table of, 135
Wire gauges, 40
  ,, , stranded, 40
"Wireless" frequency, 114
  ,, waves, 31, Chap. VII etc.
  ,, ,, , detection of, Chap. VII.
  ,, ,, , production of, Chaps. VII., XIII.
  ,, ,, , propagation of, 128, Chap. VII.
  ,, ,, , short, 135

Xs, 133

*Printed in Great Britain by Wyman & Sons Ltd., London, Reading & Fakenham*

R.B.A N.M'S H.S (M) LIBRARY
B'lore-42
Accession No; 1765
U.D.C No: 538.56/(HUT)
Date; 5.7.81 N26
24 JUL 1986
N26

R. B. A. N. M'S
High School (Main) Library

BOOK CARD

uthor HUTCHINSON (Robert W).
A first course in
eless.
1705.
B.56 (HUT) N26

| Card No. | Due Date |
|---|---|
| | 4 JUL 1986 |

R.D.A.V.M.'s High School (Main)
LIBRARY